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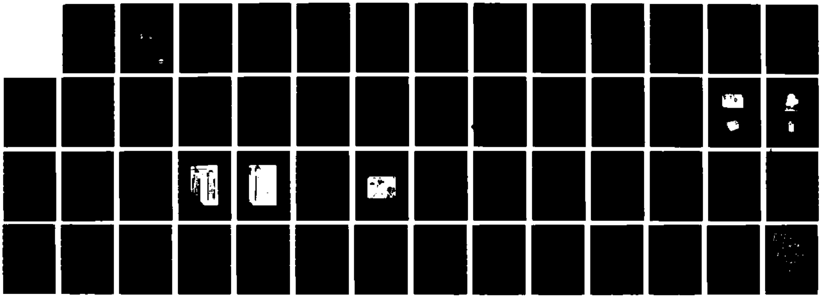

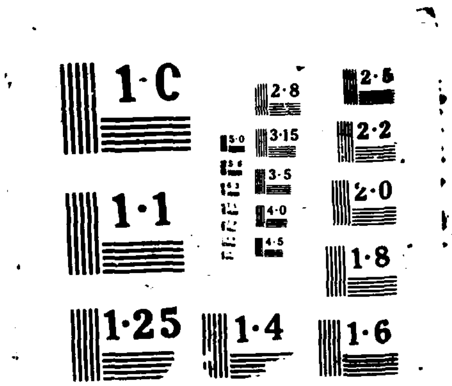
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MAN RATING THE B-1B MOLECULAR SIEVE OXYGEN GENERATION SYSTEM

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August 1987

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USAF SCHOOL OF AEROSPACE MEDICINE
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This report sets forth the findings of a test and evaluation (man rating) of the molecular sieve oxygen generation system developed for the B-1B Long Range Combat Aircraft. A series of unmanned and manned tests, covering the range of aircraft operating conditions, were conducted on a duplicate of the aircraft breathing system which was assembled in an environmental chamber. The control variables were cabin and aircraft ambient pressure, inlet air temperature and pressure, cabin temperature, and demand flow; and the dependent variables were oxygen concentration, pressure swings in the mask, and time required for backup oxygen to reach the crew after rapid decompression (RD).

Oxygen output met or exceeded specification requirements for all but two test points. Under nominal aircraft operating conditions and the maximum average demand flow of 160 liters per minute (lpm), oxygen concentration fell slightly below specification requirements at 25,000 and 28,000 ft cabin altitude. These discrepancies are not considered significant (i.e., will not compromise crew safety), because the probability is very slight that a demand

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flow rate as high as 160 lpm will ever occur (tests showed that 6 persons taking moderately heavy, rapid breaths generated 135 lpm average demand at ground level). Furthermore, the oxygen partial pressure, in the worst case, was equivalent to breathing air at only 4,000 ft pressure altitude. The breathing characteristics of the system met specification requirements and were satisfactory to the test subjects except for a slight, sporadic pressure oscillation in the regulated breathing gas. The oscillation problem has been corrected by a minor modification to the breathing regulator.

The purging system, designed to minimize the delay in receiving backup oxygen at the breathing mask during RD, functioned properly but did not result in delivery of oxygen within the specified time limit (4 sec for 90% oxygen and 10 sec for 98% oxygen, measured at the regulator outlet). A modification which automatically shuts off power to the oxygen concentrator for 3 sec after activation of the backup oxygen system was tested and produced much faster delivery of oxygen to the mask. Five simulated RDs at 30,000 ft cabin altitude resulted in an average delay of 6.1 sec before the mask oxygen concentration reached 90%, and an average delay of 8.6 sec before the concentration reached 98%. The average delay period for 5 tests performed at a 40,000 ft cabin altitude was 6.9 sec for 90%, and 10.5 sec for 98% oxygen concentration. These delay periods are considered acceptable from a physiological standpoint, on the basis of several RDs performed on human subjects breathing from a standard USAF oxygen delivery system in which oxygen delivery was deliberately delayed to simulate B-1B MSOGS performance. Nevertheless, we recommend that an in-flight RD be performed (with a backup pilot breathing 100% oxygen from a portable source) to test the modified MSOGS under actual conditions.

Subject to implementation of the modification to reduce the delivery time of backup oxygen during RD, the B-1B breathing system fully demonstrated its capability to provide sufficient quantities of physiologically acceptable breathing gas throughout the operational limits of the aircraft.

CONTENTS

Figures

(Cont'd. on next page)

CONTENTS: Figures (Cont'd.)

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CONTENTS: Figures (Cont'd.)

Tables

MAN RATING THE B-1B MOLECULAR SIEVE OXYGEN GENERATION SYSTEM

INTRODUCTION

A new aircrew breathing gas system has been developed for the B-1B long-range combat aircraft. The molecular sieve oxygen generation system (MSOGS) uses pressure-swing adsorption to separate oxygen from nitrogen in the engine bleed-air stream. Oxygen-enriched breathing gas flows to the crew, and the nitrogen-rich remnant vents overboard. Thus, an unlimited oxygen supply, generated from the atmosphere around the aircraft, replaces the limited liquid oxygen stores which could restrict mission duration or interfere with remote basing opportunities. While utilizing previous MSOGS test and man-rating experience, the U.S. Air Force School of Aerospace Medicine (USAFSAM) conducted full-scale testing of the B-1B MSOGS, and validated its use for manned flight.

SYSTEM DESCRIPTION

The B-1B MSOGS comprises a concentrator assembly, a release valve, two purge valves, and six breathing regulators with interconnecting plumbing (Fig. 1). The system was designed and developed by Normalair-Garrett Limited (of the United Kingdom), and by Rockwell International, prime contractor for the B-1B aircraft. Under all possible B-1B flight conditions, the breathing system provides the aircrew with physiologically adequate gas--either MSOGS product from the concentrator, or Aviator's Breathing Oxygen (ABO) from a backup oxygen supply (BOS). (The BOS is a stored high-pressure gaseous supply, procured separately from the MSOGS.) If cabin altitude exceeds 28,000 ft, or if the crew manually selects backup oxygen, the release valve supplies oxygen from the BOS. Otherwise, MSOGS product gas of variable oxygen content is the primary breathing gas delivered to the aircrew mask. Brief descriptions of these individual components are in the following sections.

Concentrator Assembly

The concentrator assembly (Fig. 2) performs the actual oxygen-nitrogen separation process in six canisters filled with Union Carbide MG-3 zeolite molecular sieve. The technical details of pressure swing adsorption air separation, well described previously (9, 11), are not repeated here. Engine bleed air is precooled to approximately 100 °F, dehumidified, filtered, and pressure-regulated to about 32 pounds per square inch gauge (psig) before entering the zeolite beds. Electrical solenoid inlet and vent valves on each canister operate sequentially, under control of an electronic control unit, to

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EDITOR'S NOTE: For the convenience of the reader, all figures (Nos. 1-30) have been grouped at the close of the text; and a list of abbreviations and acronyms is provided at the end of the report.

produce the correct pattern of air charge, product gas flow, purge flow, and vent to ambient in each bed. The valve timing cycle is fixed at about 9 sec; product gas oxygen concentration is optimized, but not directly controlled. The electronic control unit also processes signals from several pressure-and-temperature sensors which are used to verify proper concentrator function (or to detect potential malfunctions).

Release Valve

The release valve (Fig. 3) provides stored gaseous oxygen from the BOS as the breathing gas when manually selected by the crew or if cabin altitude exceeds 28,000 feet. The aircrew might select the BOS in case of problems with the aircraft bleed air supply, MSOGS concentrator failure indication, and smoke or fumes in either the cabin air supply or the MSOGS product gas--or if the aircrew experience airsickness, hypoxic symptoms, or any other physiologic distress. The crew can manually trigger the release valve by means of an electrical toggle at the copilot station, or with a switch on the valve case in the central equipment bay (CEB). In the automatic release mode, an aneroid in the valve case senses cabin altitude to operate the valve at 28,000 (+/-1000) ft. Upon cabin repressurization or descent below 28,000 ft, the valve automatically closes. When the release valve is activated, the reduced pressure (about 80 psig) of the ABO from the backup supply closes a check valve, thus preventing backflow into the concentrator and simultaneously stopping flow of MSOGS product gas into the breathing system. When this pressure subsides due to depletion of the BOS or closure of the release valve, the check valve opens and breathing gas is again supplied from the MSOGS concentrator.

Purge Valves

During normal operation, the MSOGS delivers breathing gas with a physiologically adequate oxygen concentration, which may be as low as 25% oxygen at the normal cabin altitude of 8,000 ft. Upon activation of the release valve, high oxygen content gas from the BOS should reach the crew as quickly as possible to minimize the risk of hypoxia or of toxic gas exposure. The length of breathing gas tubing from the CEB to the crew stations contains MSOGS product gas which could delay delivery of backup ABO. Therefore a pair of valves (Fig. 4), one near the pilot station and one near the copilot station, purge MSOGS product gas from the breathing gas tubing in order to prevent mixture with the ABO released from the BOS and thus preclude delay of oxygen delivery. These purge valves open concurrent with the release valve for a short predetermined time (a few seconds, or tenths of a second), dump gas at a very high flow rate, and then close quickly to avoid bleeding-off the backup supply.

Breathing Regulators

A non-dilution, pressure-demand regulator (Fig. 5) delivers MSOGS breathing gas to the aircrew mask at appropriate pressure. Because the concentrator product gas is physiologically adequate but variable in oxygen content, accurate dilution is impractical. Hence a non-dilution regulator is dictated.

The molecular sieve filtration capability is also preserved by using the gas undiluted, with no opportunity for contaminants to be introduced through a dilution port. The regulator operates with the relatively low inlet pressure (10 psig) expected in this breathing system, and supplies automatic pressure breathing above 30,000 ft cabin altitude. The regulator incorporates an anti-suffocation valve, a compensated outlet relief valve, and a NORM/PRESS mode selector for switching from demand to safety pressure breathing. For the four primary crew members, the regulator is ejection-seat mounted; the two auxiliary instructors wear the lightweight (0.99-lb) regulator on a harness mount.

Physiological Design Parameters

USAFSAM has assisted the B-1 System Program Office in developing MSOGS performance specifications which are compatible with the physiological requirements of the aircrew. The MSOGS design aims to provide 40 liters per minute (lpm) ATPD (ambient temperature and pressure, dry) average breathing gas flow for each of four primary crew members. Minimum oxygen concentration of this breathing gas will be equivalent to breathing air at sea level, or sufficient to prevent alveolar oxygen tension from falling below 30 mm Hg upon rapid decompression (RD)--whichever is higher (Fig. 6). Keeping alveolar oxygen tension above 30 mm Hg prevents incapacitation of the crew due to the hypoxic effects of rapid decompression (4). A minute volume of 40 liters is sufficient to sustain such moderate to heavy work loads as might be encountered during a combat mission (7). The 160 lpm total average flow (40 x 4 primary crew) satisfies the flow requirements of paragraph 3.4.1, MIL-D-19326F: General Specification for Design and Installation of Liquid Oxygen Systems in Aircraft (16), and meets the peak flow demands of an augmented training crew of 6 (each breathing at 40 lpm average flow more than 90% of the time) (2). The delivery plumbing and breathing regulator at each crew station must therefore pass a peak flow of at least 126 lpm (40 x pi).

Negative mask pressures and corresponding pressure swings required to generate given dynamic flows define the breathing resistance or "breathability" of the system. NATO and the Air Standardization Coordinating Committee (ASCC) have published (12, 13) recommended mask pressure limits against which the B-1 MSOGS was compared. However, breathing mask pressure fluctuations are strongly influenced by the design of the mask itself. Since the B-1 system is obliged to use the MBU-12/P mask which has known limitations, the MSOGS is not expected to meet NATO/ASCC standards. Instead, MSOGS is required to pass at least 126-lpm steady flow with a regulator outlet pressure between -1.0 and 0.0 in. of water (normal mode), up to 30,000 ft altitude. Above 30,000 ft, the specification calls for regulator outlet pressure to increase gradually to between 8.0 and 11.0 in. of water at 45,000 ft. In the safety pressure (PRESS) mode, regulator outlet pressure shall be 1.0 to 1.5 in. of water higher than in the normal (NORM) mode. In response to a rapid cabin decompression to high altitude, the MSOGS release valve and purge valves are designed to supply ABO from the backup supply to the aircrew as rapidly as possible. Human physiological studies conducted at USAFSAM and other institutions (1, 3, 4, 5, 6) indicate that a delay of more than 10 sec in oxygen delivery might cause temporary incapacitation of some crew members. Therefore, the system specification requires 98% oxygen delivery within 10 sec of decompression to an altitude above 28,000 ft.

TEST EQUIPMENT AND METHODS

To simulate the aircraft installation as accurately as possible, a full-scale wooden mockup of the B-1B crew compartment and central equipment bay was constructed in a large environmental chamber. MSOGS components, including actual aircraft hardware, were installed in their flight configuration. Figure 7 is a schematic drawing of the test setup, with the key to the instrumentation provided on the facing page. Shown in Figures 8 and 9 are different views of the test rig installed in the environmental chamber.

Clean, dry instrument air, regulated with reference to aircraft pressure, was supplied to the concentrator assembly through 3/4-in copper pipe. The exhaust chamber, simulating aircraft ambient altitude, was located apart from the main test chamber, and required about an 80-ft run of 4-in. diam PVC pipe from the concentrator. Large diameter pipe was used to minimize back pressure at the exhaust outlet. A 4-ft section of 1.75-in. hose, smoothly necked up to the larger diameter, connected the concentrator exhaust port to the PVC pipe, in a manner similar to that of the aircraft tubing connecting the concentrator to the overboard dump plenum. Exhaust pressure (P6 in Fig. 7) which was monitored at the distal end of this hose, pulsed about 10% above the exhaust chamber pressure as the vent valve on each zeolite canister opened. Since the exhaust pressure behavior in an actual aircraft installation is not known, we adjusted the exhaust chamber pressure so that, at the monitoring point, the mean pressure equalled the desired aircraft pressure altitude.

Three major areas of performance were tested: (a) oxygen concentration; (b) pressure/flow output "breathability"; and (c) post-decompression time required for backup oxygen to reach the crew. Some other aspects of system performance were also checked: altitude pressure breathing schedule; compensated relief valve function; antisuffocation valve function; release valve electrical and aneroid actuation; breathing line pressure drop; bleed air consumption; and safety pressure (PRESS) open-mask flow.

Oxygen Concentration

Unmanned tests were conducted from ground level (GL) to 40,000 ft cabin altitude (release valve disabled to prevent release of backup oxygen at 28,000 ft), and from 10,000 to 45,000 ft aircraft altitude, with the cabin pressurized to 8,000 ft. Oxygen concentrating capability was tested at steady demand flows ranging from 40 to 240 lpm ATPD, at ambient temperature (65 to 75 ^{o}F), with supply pressures of 25, 50, and 75 psig. Nominal aircraft operating conditions of 100 ^{o}F inlet air temperature, 120 ^{o}F CEB temperature, and 32 psig inlet air pressure were also simulated. Demand flows and altitudes exceeding B-1B specification requirements (160 lpm and 42,000 ft respectively) were investigated because similar systems may be employed on other aircraft with different performance capabilities.

The effect of temperature extremes on oxygen concentrating capability was checked at GL. A low-temperature test was conducted by packing the concentrator assembly in dry ice and soaking for 18 hr. The bed housing temperature reached a low of -72 ^{o}F during the soak, but rose to -40 ^{o}F at the time the test began, and to 10 ^{o}F by the end of the test run. Several tests were run with elevated environmental and inlet air temperatures at both GL and altitude.

Tests at 120 ^{o}F CEB temperature were conducted by heating the entire test chamber, while 160 ^{o}F tests were completed by heating only the concentrator assembly with a thermal blanket. During all test work, the precooler (heat exchanger) on the concentrator assembly that cools the inlet bleed air was not operating, because we had no capability to supply liquid coolant. Furthermore, the ambient inlet air supply had to be heated instead of cooled to simulate most operational conditions. Temperatures as high as 135 ^{o}F at the concentrator inlet were tested; normal operating procedures call for the crew to shut down MSOGS if the inlet temperature exceeds this value.

Breathing Performance

The breathing regulators were initially tested separately from the rest of the MSOGS components by using the test setup shown in Figure 10. This setup permitted precise control of inlet pressure, and allowed us to observe regulator response to rapid decompression. (The large primary test chamber does not have RD capability.) Although the MSOGS specification defines breathing performance in terms of regulator outlet pressure as a function of steady flow demand, both steady and cyclic flow tests were conducted to better characterize response, and to permit comparison with NATO/ASCC standards (12). Steady flow tests were run up to 126 lpm, with regulator inlet pressures of 10 and 30 psig at GL, and 10 psig at 8,000 ft. The dynamic tests used an MBU-12/P mask, mounted on a manikin head, with a programmable bellows-type breathing machine (Technology Inc., Variable Profile Breathing Simulator) generating sinusoidal waveform breaths at rates up to 50/min (maximum peak flow was 210 lpm; maximum rate of change of flow was 17.5 liters/sec^2). Manned breathing trials, at altitude, and both unmanned and manned rapid decompressions were also carried out using this test setup. Decompressions were conducted from 8,000 to 45,000 ft (unmanned) or 42,000 ft (manned), with 90% of the pressure change occurring in 1.6 and 2.5 sec, respectively. All regulator tests were completed at ambient temperature.

To evaluate the breathing performance of the entire aircraft system (Figs. 1, 7), unmanned steady and dynamic flow tests were conducted at ambient temperature at GL and at 42,000 ft, with the cabin pressurized to 8,000 ft. Regulator outlet pressure and/or mask pressure were measured at the pilot station under two flow conditions: (a) minute volumes of up to 126 lpm steady flow and 67 lpm dynamic flow (200 lpm peaks) were drawn from the pilot station (simulates breathing demand of one crewman); and (b) with the same flow rates at the pilot station as in (a), the total system demand was boosted to the design limit of 160 lpm by bleeding off the necessary flow from another crew station. Two groups of 5 and 6 human subjects, respectively (Fig. 11), also tested the system over a wide range of altitudes and breathing demands. To achieve significant variation in flow demand, the subjects breathed in four different patterns: (a) at rest according to their own individual rhythm (at random); (b) at random with mild exercise; (c) with moderately deep synchronized inhalations; and (d) at rest, randomly, with supplemental steady flow from the CEB auxiliary breathing station to generate a total system demand of 160 lpm. Subjective evaluations of system breathability were solicited from the volunteers after each manned test.

Rapid Decompression

As just noted, the MSOGS breathing regulators were independently tested for their response to actual decompressions. Because the large test chamber does not have RD capability, RDs of the entire MSOGS system were simulated by capping the release valve aneroid port at GL, ascending to a pressure altitude above 28,000 ft, and then uncapping the aneroid port to actuate the release valve. Later, after aneroid function was verified, multiple simulations were conducted by leaving the port capped and simply turning the manual switch at altitude, thus eliminating the need for repeated ascents and descents of the chamber to reset the aneroid. The primary purpose of these simulated RDs was to measure the time required for 98% backup oxygen to reach the aircrew mask at the pilot station. For this purpose, analysis showed that this very simple simulation technique adequately represented the events of an actual decompression. We expected oxygen delivery time to be a complex function of purge valve open time, flow demand, initial oxygen concentration, final altitude, and system pressure.

Oxygen delivery time was measured by using three different test configurations. Configuration No. 1 conformed to test procedures described in the MSOGS specification: The MSOGS breathing lines were charged from a cylinder containing gas of 21% oxygen concentration in one case, and 50% oxygen in the second case; post-RD cabin altitude was set in the chamber; a steady-demand flow of 15 lpm ATPD was drawn from the pilot station; the release valve was actuated; and the time from energization of the purge valves to arrival of 98% oxygen in-the mask was measured. This test represents a theoretical worst case of low initial oxygen concentration in conjunction with a low demand flow. (Normally, these two conditions are mutually exclusive, because concentration varies inversely with flow.) Configuration No. 2 was similar to No. 1, except that the setup comprised the complete MSOGS (Fig. 7). The concentrator inlet pressure was 32 psig and the MSOGS oxygen output was treated as a dependent variable. Because of the low-demand flow rate (15 lpm) and high cabin altitude (30,000 ft), the initial oxygen concentration was 94%. Test configuration No. 3 utilized the same procedures as No. 2, except that flow demand was generated by human subjects instead of a vacuum pump.

When initial testing demonstrated that the MSOGS could not meet the specification requirement to deliver 98% oxygen within 10 sec of rapid decompression, the system was modified to improve its RD performance. A shutoff valve was installed between the charging cylinder (configuration No. 1) and the check valve to determine if isolating the gas supply at the moment of RD would reduce the delivery time of ABO. (Previous testing had indicated that pressure losses in the BOS circuit during purge valve operation were preventing the check valve from closing; hence, the supply gas continued to flow, thus diluting the ABO). This configuration (No. 4) was then tested in the same manner as configuration No. 1, except that the shutoff valve was closed simultaneously with release valve actuation. After several tests demonstrated the effectiveness of the isolation technique, the B-1B contractor, Rockwell International, developed a design modification which automatically interrupted power to the concentrator for 3 sec beginning with release valve actuation. Configuration No. 5 incorporated this design change into the test rig (Fig. 7), and steady-flow tests were conducted in the same manner as previously described. The initial line concentration was controlled by venting additional flow at one of the remaining breathing stations, and initial line pressure was controlled by adjusting the concentrator inlet pressure.

TEST RESULTS

MSOGS generally meets the specified physiological design requirements. With minor exceptions, oxygen concentrating capability is satisfactory throughout the operational envelope. Oxygen output characteristics are very similar to other molecular sieve systems. Overall, breathability is judged satisfactory, although (as expected) not up to NATO/ASCC standard (12). Delivery of oxygen after RD initially did not meet the 10-sec specification requirement. System modification to turn off electrical power to the concentrator improved decompression performance to just within this specified limit. Miscellaneous tests of line pressure drop, open outlet flow, bleed air consumption, and release valve actuation at altitude were completed satisfactorily. Antisuffocation valve response was out of specification limits.

Oxygen Concentration

Oxygen content of the MSOGS product gas varies inversely with mass flow through the zeolite beds. Curves relating oxygen output of the MSOGS concentrator assembly to flow, altitude, inlet pressure, and temperature are generally very similar to the output curves of other pressure-swing adsorption oxygen concentrators tested at USAFSAM (8*, 10, 11, 14, 15), except that the B-1B unit has greater flow capacity due to its six-bed design. Illustrated in Figures 12 and 13 is the relationship between oxygen concentration and demand flow at GL for various inlet pressures and several temperature conditions. Also shown in Figure 12 is the variation in oxygen output with inlet pressure at ambient temperature (72 ^{O}F). Because pressure-reducing valves on the concentrator assembly regulate input pressure to 32 (+/-3) psig, higher pressures produce nearly identical curves. In Figure 13, concentrator output under extreme temperature conditions, both hot and cold environments (CEB) and hot inlet air, are compared to ambient conditions (72 ^{O}F). Over the ranges investigated (-40 to 160 ^{O}F environment, 72 to 135 ^{O}F inlet air), temperature had a relatively minor effect upon oxygen concentration. This result agrees with expectations based upon the relatively flat shape of the zeolite adsorption isotherms in the subject temperature range.

The cabin pressurization system of the B-1B normally maintains the crew compartment at an absolute pressure of 10.9 (+/-0.2) psi, or an altitude of about 8,000 ft, during flight above that level. A series of tests simulating pressurized cockpit conditions at aircraft altitudes between 10,000 and 45,000 ft, and the inlet air and CEB at 72 ^{O}F, generated the oxygen concentration curves in Figures 14 and 15. These figures show the oxygen output of the MSOGS as a function of demand flow for various altitudes, with 25-psig and

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50-psig inlet pressures, respectively. Test results with 75-psig inlet pressure were not remarkably different from those with 50 psig. Presented in Figures 16 and 17, respectively, are data grouped by altitude at 10,000 and 45,000 ft. Illustrated in Figure 18 is the same output relationship with altitude when operating at nominal aircraft conditions (inlet air = 100 ^{o}F and 32 psig, and CEB = 120 ^{o}F). At altitude, the decrease in oxygen output with increasing temperature is more pronounced than at GL, as seen by comparing Figures 13 and 19. In all cases, oxygen output varied inversely with product mass flow, and minimum concentration requirements were met at flows up to the specification maximum of 160 lpm.

A series of tests simulating loss of cabin pressure produced Figures 20-24 (analogous to Figures 14-18 with the cabin intact). Comparing Figures 17 and 23, or 18 and 24 illustrates that operation of the MSOGS in a high-altitude cabin improves performance significantly. In fact, the oxygen output provides excellent hypoxia protection up to a cabin altitude of 30,000 ft (Air Force flight regulations still require descent to below 25,000 ft in the event of cabin depressurization, because of the hazards of decompression sickness.) Analysis of Figure 24 shows that specification requirements of sea-level physiological equivalence were not completely met at cabin altitudes of 25,000 and 28,000 ft. That is, curve B drops below the 63% oxygen requirement at flows above 147 lpm, and curve A drops below the 70% oxygen requirement at flows above 125 lpm. Nonetheless, we consider the MSOGS safe to fly (from a hypoxia protection standpoint) because: (a) the test point with the largest variance from specification (7 percentage points low in oxygen concentration at 28,000 ft and 160 lpm flow) provides an oxygen partial pressure equivalent to breathing air at less than 5,000 ft; (b) testing with an augmented crew of six subjects demonstrated that flows above 120 lpm will seldom occur; and (c) upon depressurization, descent below 25,000 ft is required. Presented in Table 1 is a summary of MSOGS performance in unmanned tests; and summarized in Table 2 are the manned system tests.

Breathing Performance

Subjective comments on the breathability of the MSOGS regulators--when tested independently (Fig. 10), and when tested as part of the MSOGS (Figs. 7, 11)--indicate adequate breathing gas delivery pressure under all but the most extreme conditions (deep and rapid inhalations approaching 60 lpm volume, in conjunction with regulator inlet pressure of less than 15 psig). In these circumstances, mask pressure swings of up to 25 in.-wg, with negative pressure of about 16 in. of water during inhalation, resulted in visible mask collapse and subject complaints of loss of mask pressure and air starvation. This type of respiration, simulating anti-G straining maneuvers, should not be required of crewmen while flying the B-1B weapons system. Under normal breathing conditions, subjects described the system as comparable to or better than the standard Air Force CRU-73 regulator, particularly in the safety pressure (PRESS) mode which further reduced inspiratory resistance. Initial production standard regulators exhibited a sporadic oscillatory "buzz" with certain mask sizes, facial shapes, or flow conditions. This flaw had no effect on performance but was, nonetheless, subjectively distracting. Minor adjustment of the size of the orifice feeding outlet pressure back to the sensing diaphragm eliminated the problem in subsequent regulators.

TABLE 1. B-1B MSOGS OXYGEN OUTPUT--UNMANNED

Temperatures (°F) Inlet air	CEB	Inlet air press. (psig)	Altitude (X 1000 ft) Cabin	Aircraft	Oxygen output (%) Product 40	Gas 80	Minute 120	Volume 160	(1 ATPD) 200	240
A	A	25	GL	GL	67	46	38	34	32	--
A	-10	25	GL	GL	71	48	40	36	34	33
A	A	50	GL	GL	83	68	54	47	44	42
100	120	50	GL	GL	81	63	51	45	42	39
135	160	25	GL	GL	54	40	34	31	29	--
A	A	25	8	10	88	64	51	45	41	39
100	120	32	8	10	82	60	50	45	41	39
A	A	50	8	10	90	79	67	59	54	50
160	120	25	8	15	70	54	44	39	36	33
A	A	25	8	20	91	68	54	48	44	41
100	120	32	8	20	83	62	52	47	44	41
A	A	50	8	20	91	84	72	64	57	53
A	A	25	8	30	89	70	58	51	47	41
100	120	32	8	30	82	61	53	48	45	42
A	A	50	8	30	92	83	73	64	59	55
160	120	25	8	40	60	48	42	38	34	32
A	A	32	8	42	91	74	61	54	50	47
100	120	32	8	42	79	61	52	48	44	42
A	A	25	8	45	91	68	57	51	47	--
A	A	32	8	45	89	74	61	54	50	48
A	A	50	8	45	92	83	72	63	59	55
100	120	32	8	45	77	59	51	48	44	42
A	A	25	10	10	89	65	52	46	43	40
100	120	32	10	10	84	63	51	46	42	-
A	A	50	10	10	91	81	70	60	54	51
A	A	25	20	20	92	82	68	58	53	49
100	120	32	20	20	88	74	64	55	50	-
A	A	50	20	20	92	86	81	73	67	62
A	A	25	25	25	95	89	80	69	61	56
100	120	32	25	25	90	78	68	60	55	-
A	A	50	25	25	95	91	86	80	75	70
A	A	25	28	28	95	92	83	73	65	60
100	120	32	28	28	90	81	70	63	57	-
A	A	50	28	28	94	92	90	85	80	74
A	A	25	40	40	95	94	93	90	84	78
A	A	50	40	40	95	93	90	90	86	84

A = ambient temperature (65 to 75 °F)
CEB = central equipment bay

TABLE 2. B-1B MSOGS OXYGEN OUTPUT--MANNED*

Breathing description	Altitude (x 1000 ft) Cabin	Altitude (x 1000 ft) Aircraft	Inlet air pressure (psig)	Product minute volume (1 ATPD)	Product pressure (psig)	Minimum regulator inlet pressure (psig)	Oxygen output (%)
				6-Man Test			
Resting	GL	GL	30	67	26	24	60
Exercise	GL	GL	30	120	24	22	49
**Synchronous	GL	GL	30	135	22	14	45
Resting	8	8	30	73	26	22	75
Exercise	8	8	30	121	25	20	57
**Synchronous	8	8	30	170	24	14	50
Resting	15	15	30	57	25	24	86
Exercise	15	15	30	106	25	22	73
Resting	20	20	30	65	25	24	90
Exercise	20	20	30	105	25	23	70
				5-Man Test			
160 lpm	GL	GL	30	152	23	20	41
160 lpm	15	15	30	173	23	20	54
160 lpm	20	20	30	157	23	21	68
Resting	28	28	30	46	25	24	93
Resting	8	10	31	44	24	21	87
Exercise	8	10	31	70	23	21	79
160 lpm	8	10	31	162	22	20	50
Resting	8	20	33	46	23	20	88
160 lpm	8	20	33	173	20	18	53
Resting	8	30	36	67	22	18	84
160 lpm	8	30	36	174	19	16	54
Resting	8	40	38	57	22	19	85
Exercise	8	40	38	71	22	19	83
160 lpm	8	40	38	156	20	16	60
Resting	8	50	39	65	22	18	85
160 lpm	8	50	39	162	20	16	60

*Refer to report section entitled "Test Methods" for breathing descriptions.

**Synchronous inhalations

(Product gas pressure was measured 8 ft downstream of the concentrator outlet.)

The specification requirement to provide 126 lpm steady flow, with regulator outlet pressure not less than -1.0 in.-wg NORM mode, was met by four of seven regulators tested. Steady-flow performance of the best and worst regulators is shown in Figure 25, at ground level, with 10-psig inlet pressure in NORM mode. Every regulator's outlet pressure remained satisfactory through at least 100 lpm. At GL with 30-psig inlet pressure, or at 8,000 ft with 10-psig inlet pressure, or in the safety pressure (PRESS) mode, all regulators met the steady-flow requirement. Therefore, we do not consider this deficiency to have any significant operational impact or to present a hazard to safe manned flight. Steady-flow tests of regulator altitude pressure breathing schedules at 10- and 126-lpm flow resulted in satisfactory performance, similar to that shown in Figure 26.

As expected, dynamic testing showed that the MBU-12/P mask, B-1B MSOGS regulator combination could not meet NATO/ASCC mask pressure swing standards. Performance was reasonable up to 150-lpm peak flow, however, with most of the regulators staying within or near ASCC limits up to that point (Fig. 27). At 210-lpm peak flow, negative mask pressures of nearly 20 in.-wg were observed; but we do not anticipate B-1 crews requiring such large flows. System dynamic performance at GL (Fig. 28) shows slightly larger mask swings, with greater negative and positive mask pressure excursions. Importantly, however, increasing total system demand to the specification maximum of 160 lpm has relatively little effect upon dynamic performance, thus indicating that the system capacity is adequate. Also, as cabin altitude increases, breathability improves. All in all, dynamic performance of the MSOGS is judged satisfactory.

Breathing regulator antisuffocation valves began to crack open slightly before the design point of -4.5 in.-wg regulator outlet pressure. At -6.0 in.-wg regulator outlet pressure, average flow of 32 lpm fell short of the specification requirement for 50 lpm. These are noncritical deviations from specified performance.

Breathing-line pressure drop from the concentrator outlet to the regulator inlet at the pilot station is illustrated, in Figure 29, for three concentrator outlet pressures at GL and 8,000 ft. Note that, when concentrator outlet pressure is 20 psig, regulator inlet pressure will fall below 10 psig for flow over about 135 lpm at GL.

Allowing open flow to ambient pressure, through a mask with the regulator in the safety pressure (PRESS) mode, results in an average of 40-lpm flow at a cabin altitude of 8,000 ft. Therefore the system will not be taxed excessively should a crewman leave his station or drop his mask with the regulator in PRESS mode during flight.

Rapid Decompression

Decompressions of the MSOGS breathing regulator demonstrated excellent relief valve capability to limit pressure excursions in the mask. Transient pressure buildup in the mask did not exceed 10 in.-wg during unmanned testing and, due to significant mask leakage, was even less during manned exposures.

Generally, a maximum of 22 in.-wg is considered physiologically acceptable for this value. Pressure breathing response of the regulators after decompression was also within specification (Fig. 26).

Results of simulated RDs of the MSOGS are summarized in Table 3. Tests conducted in accordance with the B-1B specification (Configuration No. 1, using a gas cylinder in place of the concentrator) produced excessive delivery times, as did steady flow and manned testing of the MSOGS (Configuration Nos. 2 and 3, respectively). Test results indicated that delivery time was directly proportional to initial line pressure (as expected), but no relationship was discernible between delivery time and initial concentration, or between delivery time and purge valve setting (open time).

Further testing, however, demonstrated one fairly consistent phenomenon: oxygen concentration started to increase within 1 or 2 sec of purge valve closure, then fell, and stayed depressed, usually for 10 sec or more (Fig. 30: channel 6, point A) before rising to 99% (typical ABO value). Also, while the purge valves were open, pressure at both the release valve outlet (channel 1, point B) and the concentrator outlet (channel 2, point C) dropped off. The combination of these events indicates that, while the purge valves are open, system demand is so high that flow is throttled through the reducing valve and associated plumbing of the BOS. Since pressure is low at the release valve, the check valve isolating the concentrator is not closed; and product gas is drawn through the concentrator at a high flow rate, as indicated by the large overall system flow (channel 3, point D). High flow through the concentrator means oxygen content of this gas is low, significantly diluting the choked ABO flow from the BOS. After the purge valves close, pressure at the release valve outlet, builds to 80 psig within a few seconds (channel 1, point E); and product gas flow is then checked. However, a bolus of dilute gas remains in the system; and therefore delivery of high oxygen concentration gas may be delayed for several seconds (channel 6, point F). Higher system flow rates (e.g., 60 vs. 15 lpm) result in proportionately faster oxygen delivery, as the dilute gas is removed from the system more rapidly.

Discovery of the concentrator draw-through phenomenon led to a suggestion that the concentrator be isolated from the breathing circuit while the purge valves were open. Such isolation was originally a specification requirement, but had been deleted early in system design; for placing a shutoff valve in the system at the concentrator outlet would introduce a possible critical failure mode, thus significantly reducing overall reliability. The isolation concept was evaluated by installing a manually controlled shutoff valve at the outlet of the concentrator in the breathing gas line. Delivery time was considerably reduced (Table 3: test configuration No. 4); and, as a result, Rockwell International developed the "Power Interrupt" design modification which interrupted power to the concentrator for 3 sec, beginning with release valve actuation. Without power, the electrically operated inlet valve of each bed closes and prevents further flow through the concentrator.

Results of simulated RDs of the design modification (test configuration No. 5) at 30,000 ft corresponded closely with the shutoff valve results at comparable test conditions. Additional simulated RDs were performed at

TABLE 3. B-1B SIMULATED RAPID DECOMPRESSION TEST RESULTS*

No.	Test configuration	Initial line pressure (psig)	Initial oxygen concen'n (%)	Steady demand flow (lpm ATPD)	Cabin altitude x 1000 ft	Time to reach noted % O_2 in pilot's mask (sec) 90	98	Purge valve setting (sec)
1	1	19	21	14	30	12	15	0.5
2	"	19	"	"	"	12	15	1.1
3	"	19	"	"	"	13	17	3.3
4	"	32	"	"	"	21	25	0.5
5	"	32	"	"	"	21	25	1.1
6	"	32	"	"	"	22	25	3.3
7	1	20	50	14	30	7	17	1.0
8	"	20	"	"	"	7	17	3.1
9	"	34	"	"	"	22	27	1.0
10	"	34	"	"	"	23	28	3.1
11	2	27	94	15	30	--	8	0.4
12	"	"	"	"	"	--	27	1.1
13	"	"	"	"	"	--	26	1.7
14	3	25	93	**	28	--	32	0.4
15	"	"	83	**	29	24	39	"
16	"	"	78	**	25	13	21	"
17	"	"	82	**	25	11	44	"
18	4	19	21	14	30	6	10	0.5
19	"	19	"	"	"	6	9	1.1
20	"	19	"	"	"	6	8	3.3
21	"	32	"	"	"	8	13	0.5
22	"	32	"	"	"	7	10	1.1
23	"	32	"	"	"	7	9	3.3
24	4	20	50	14	30	5	9	1.0
25	"	20	50	"	"	6	8	3.1
26	"	34	50	"	"	6	10	1.0
27	"	34	50	"	"	7	9	3.1
28	5	37	50	19	30	6.5	10	1.0
29	"	28	50	19	"	5.8	8.3	"
30	"	37	46	20	"	6.5	8.5	"
31	"	32	50	13	"	6.4	8.5	"
32	"	32	80	14	"	5.5	7.7	"
33	5	37	50	27	40	7.1	11.1	1.0
34	"	37	50	30	"	6.3	10.4	"
35	"	38	50	23	"	7.5	12.5	"
36	"	30	74	12	"	7.4	9.4	"
37	"	34	52	17	"	6.4	8.9	"

*Refer to report section: "Test Methods," for test configuration descriptions.

**Human subject breathing at rest.

40,000 ft as shown in Table 3. Comparing these test results with specification requirements (4-sec limit for 90% oxygen, and 10-sec limit for 98% oxygen to reach the regulator outlet) requires an adjustment factor to account for the additional time needed for breathing gas to travel from regulator outlet to breathing mask. We performed several simulated RDs, at 30,000 ft, in which oxygen concentration was first monitored at the regulator outlet and then in the mask. The additional time required for breathing gas to reach the mask at 15 lpm, ATPD demand flow varied from 1 to 3 sec (average: 2 sec). Adjusting the mask data by the average time (2 sec) results, at 30,000 ft, in an average delay time to the regulator outlet of 4.1 sec for 90%, and 6.6 sec for 98% oxygen. At 40,000 ft, the 90% and 98% average times are 4.9 and 8.5 sec, respectively. These delays are considered acceptable from a physiological standpoint, on the basis of several actual RD tests performed on human subjects breathing from a standard USAF oxygen delivery system in which the delivery of 100% oxygen was deliberately delayed to conform with B-1B performance. Nevertheless, we recommend that an actual RD be performed inflight (with a back-up pilot breathing on a portable oxygen source) to test the system under actual conditions.

RECOMMENDATIONS

Modify operational B-1B MSOGS units to shut down concentrator flow while the purge valves are open. This modification requires a relatively minor change to the aircraft electrical multiplexing (EMUX) system, and assures critical decompression performance.

After such a modification is implemented, consider performing an actual cabin decompression at altitude during flight test, with a safety pilot on a portable oxygen source. This test would verify system response and physiological adequacy in an operational environment.

Correct minor deficiencies in antisuffocation valve function by changing the characteristics of the valve spring.

Pass lessons learned in the MSOGS development process to other system engineering and weapons system development offices. Sharing these insights will simplify the development process, and will improve the final product of other advanced breathing system design programs.

CONCLUSIONS

The B-1B MSOGS, modified to prevent concentrator draw-through while the purge valves are open, is acceptable for manned use in flight without undue hazard to operational aircrews. The system shows great promise as a revolutionary new type of breathing gas supply which eliminates the logistics limitations, expense, and hazards of liquid oxygen resupply.

REFERENCES

1. Barron, C.I., and T.J. Cook. Effects of variable decompressions to 45,000 feet. Aerospace Med 36(5):425-430 (1965). [Now: Aviat Space Environ Med]

2. Bomar, J.B., Jr. Monte Carlo simulation of dynamic breathing demand for aircraft breathing systems. Abstract. In Scientific Program for 57th Annual Meeting of Aerospace Med Assoc, Nashville, Tenn., Apr 1986. Published at Washington National Airport, Washington, D.C.

3. Billings, C.E., and J. Ernsting. Protection afforded by phased dilution oxygen equipment following rapid decompression--performance aspects. Aerospace Med 45(2):132-134 (1974).

4. Ernsting, J. Prevention of hypoxia--acceptable compromises. Aviat Space Environ Med 49(3):495-502 (1978).

5. Ernsting, J., et al. Anoxia subsequent to rapid decompression. In: A. Buchanan-Barbour and H.E. Whittingham (Eds). Human problems in supersonic and hypersonic flight. Oxford: Pergamon Press, 1962.

6. Ernsting, J., et al. Hypoxia induced by rapid decompression from 8,000 feet to 40,000 feet--the influence of rate of decompression. Flying Personnel Research Committee Report No. 1324. Ministry of Defence (Air), London, Sept 1973.

7. Handbook of respiratory data in aviation. National Research Council Committee on Aviation Medicine. Washington, D.C., 1944.

8. Horch, T.C., et al. The F-16 onboard oxygen generating system: Performance evaluation and man rating. SAM-TR-83-27, Aug 1983. (Distribution limited to U.S. Government agencies only; test and evaluation; 27 June 1983. Other requests must be referred to USAFSAM/TSKD (STINFO)).

9. Lukchis, G.M. Adsorption systems. Chem Eng, 11 Jun, 9 Jul, 6 Aug 1973.

10. Miller, R.L., et al. Molecular sieve generation of aviator's oxygen: Breathing gas composition as a function of flow, inlet pressure, and cabin altitude. SAM-TR-77-40, Dec 1977.

11. Miller, R.L., et al. Molecular sieve generation of aviator's oxygen: Performance of a prototype system under simulated flight conditions. Aviat Space Environ Med 51(7):665-673 (1980). [Formerly: Aerosp Med]

12. The minimum physiological design requirements for aircrew breathing systems. Air Standardization Coordinating Committee. AIR STD 61/22, 18 Aug 1982. U.S. Gov't. Printing Office, Washington, D.C.

13. Physiological requirements for oxygen systems in new generation high performance aircraft. STANAG 3865 AMD (1st ed.), 19 Jun 1984. NATO Military Agency for Standardization, Air Board, 1110 Brussels, Belgium.

14. Stork, R.L., et al. Human compatibility testing of a 2-man molecular sieve oxygen generator. SAM-TR-78-18, May 1978.

15. Tedor, J.B., et al. Performance testing of a three-bed molecular sieve oxygen generator. Proceedings of 19th Annual SAFE Symposium, Las Vegas, Nev., Dec 1981. SAFE Assoc., Van Nuys, Calif.

16. MIL-D-19326F. General specification for design and installation of liquid oxygen systems in aircraft. Naval Air Engineering Center, Lakehurst, N.J. 08733

F I G U R E S 1 - 30

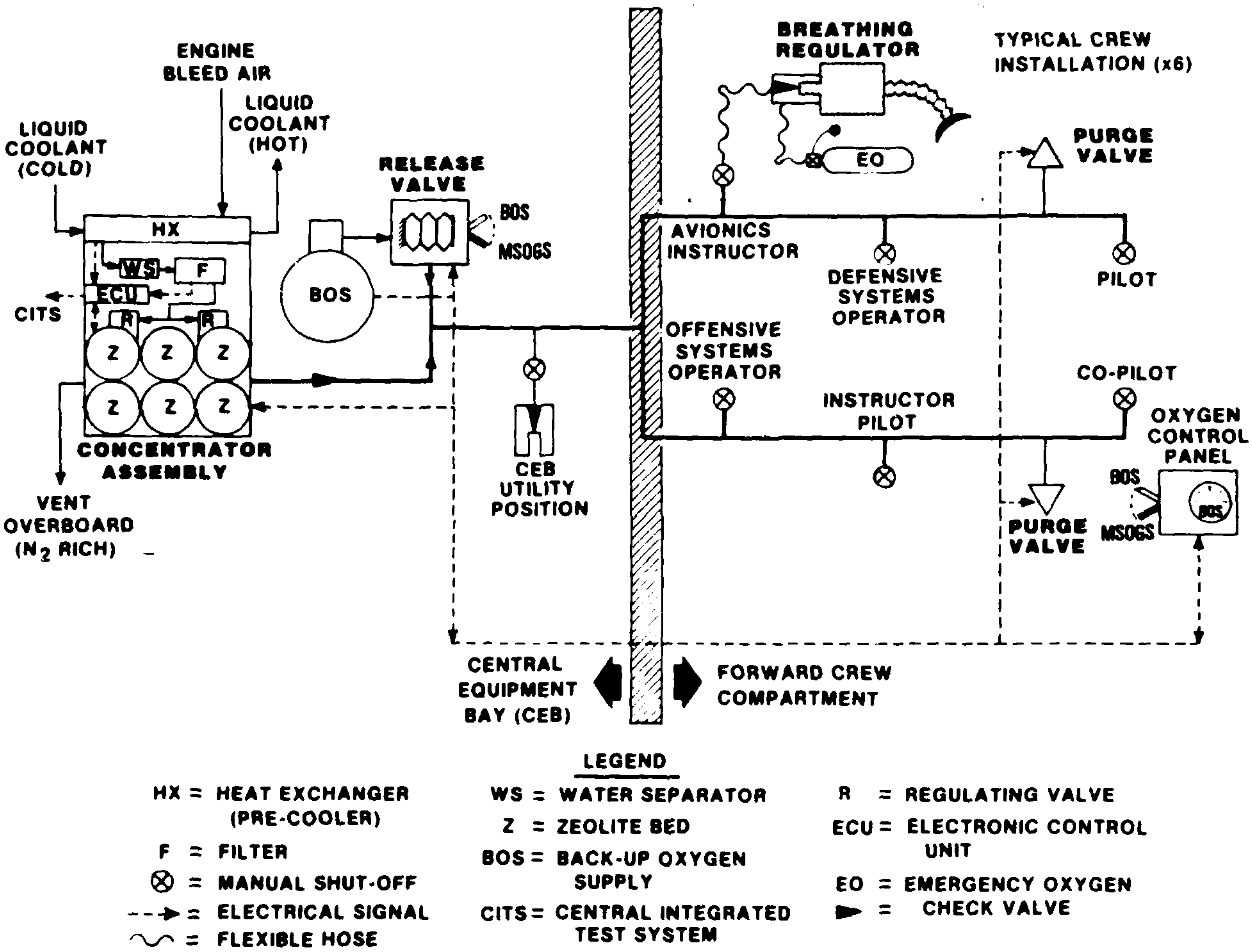

Figure 1. The B-1B crew breathing system.

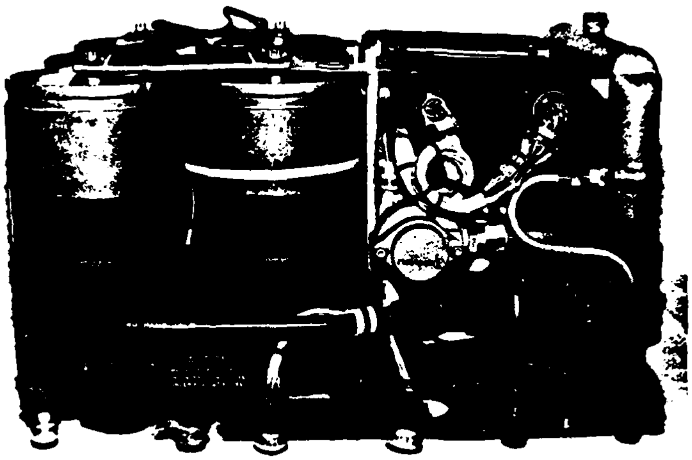

Figure 2. The concentrator assembly.

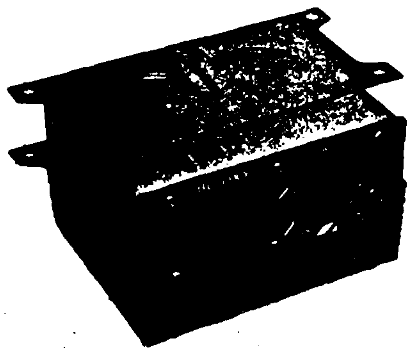

Figure 3. The release valve.

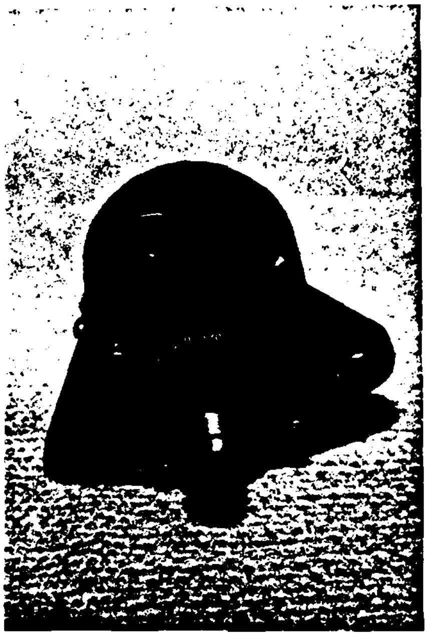

Figure 4. A purge va...

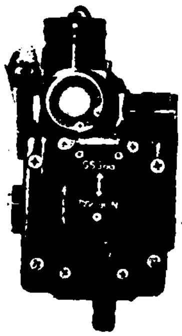

Figure 5. B-1B breathing regulator.

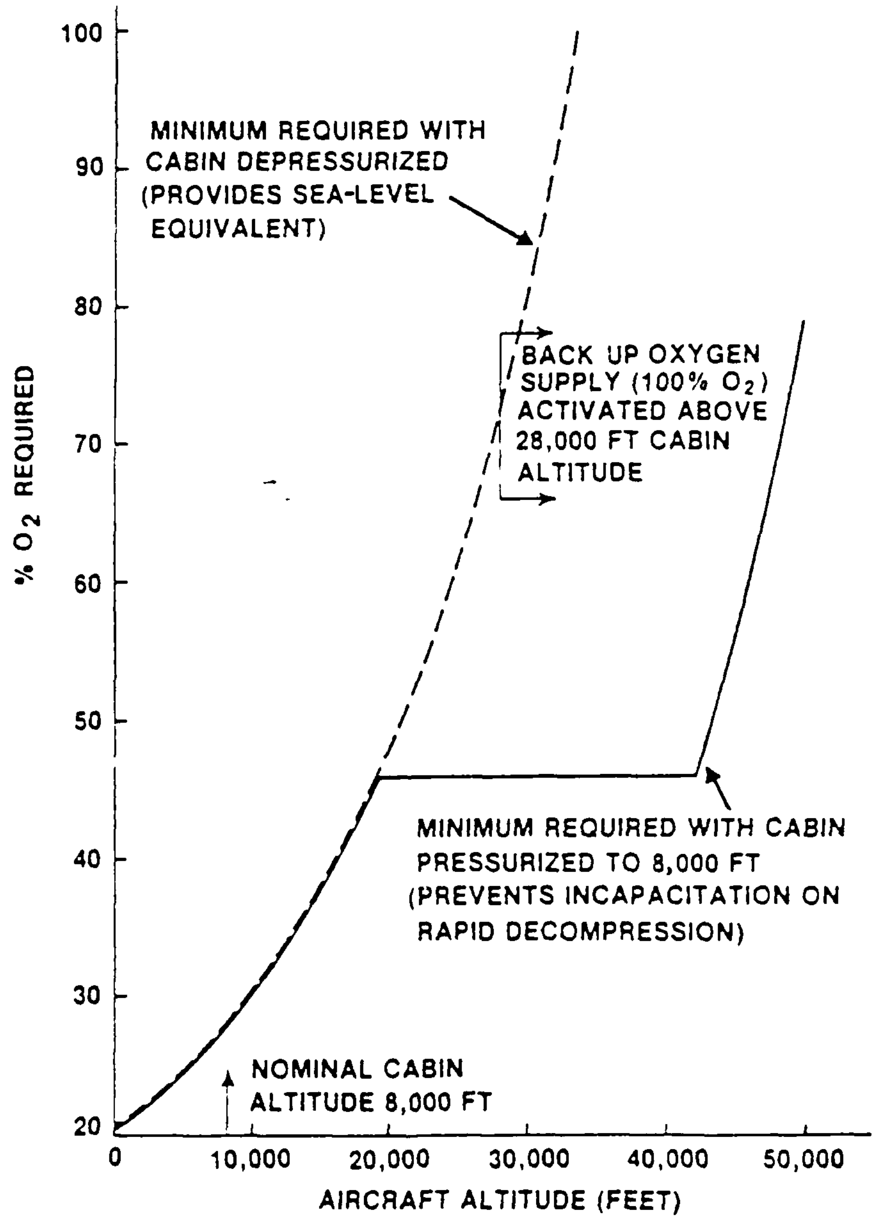

Figure 6. The B-1B MSOGS minimum oxygen requirements.

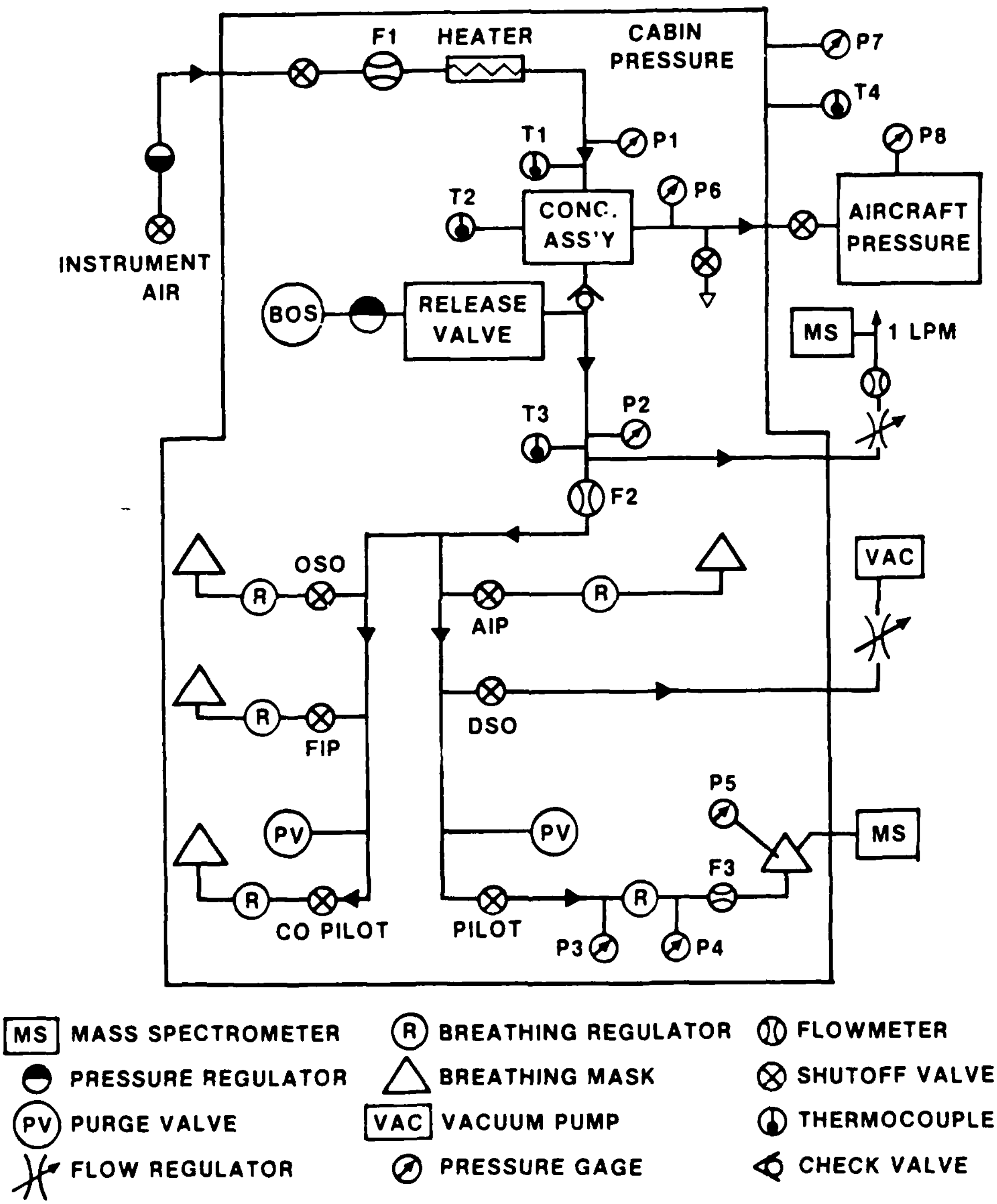

Figure 7. The B-1B MSOGS test setup.
(For Key to Fig. 7, see facing page)

KEY TO FIGURE 7

MS. Oxygen Concentration: Perkin Elmer Medical Gas Analyzer, Model 1100.

P1. Inlet Air Pressure: Validyne Reluctance Transducer, Model DP15-50.

P2. Product Gas (System) Pressure: same as P1.

P3. Breathing Regulator Inlet Pressure: same as P1.

P4. Breathing Regulator Outlet Pressure: Validyne Reluctance Transducer, Model DP15-30.

P5. Mask Cavity Pressure: same as P4.

P6. Vent Pressure: Validyne Reluctance Transducer, Model DP15-40.

P7. Cabin Pressure: Wallace Tiernan Absolute Pressure Gage, Model FA-129

P8. Aircraft Pressure: same as P7.

F1. Inlet Air Flow: Technology Inc. Mass Flowmeter, Model LFC-20 (two connected in parallel).

F2. Product Gas Flow: Technology Inc. Mass Flowmeter, Model LFC-10.

F3. Mask Flow: Fleisch Pneumotachograph #3 and Validyne Reluctance Transducer, Model P305D.

T1. Inlet Air Temperature: Omega Copper Constantan Thermocouple, Model CPSS-18U-12.

T2. Concentrator Casing Temperature: Omega Copper Constantan Thermocouple, P/N CPSS-116U-12.

T3. Product Gas Temperature: same as T1.

T4. Cabin Temperature: same as T1.

Gould-Brush Chart Recorder, Model 200.

Ampex Tape Recorder, Model PR-2200.

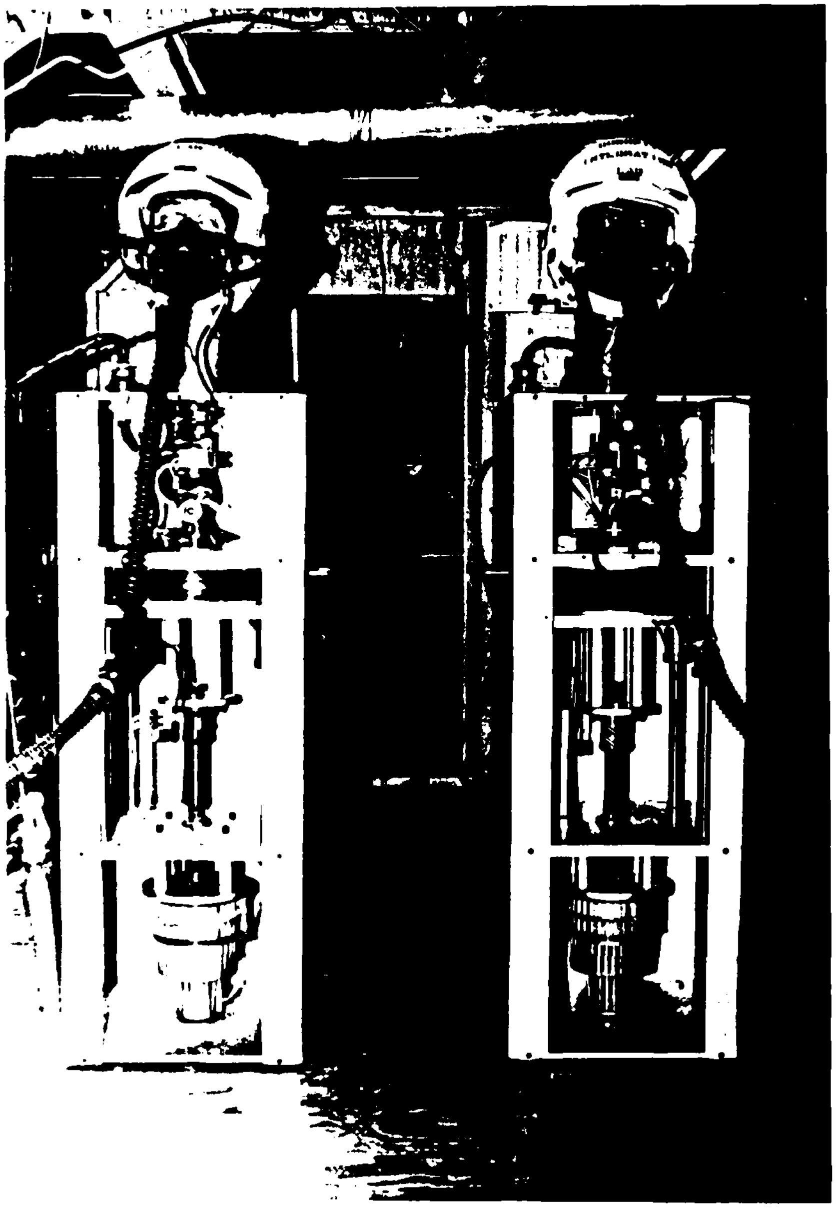

Figure 8. Test rig installed in the environmental chamber: View a.

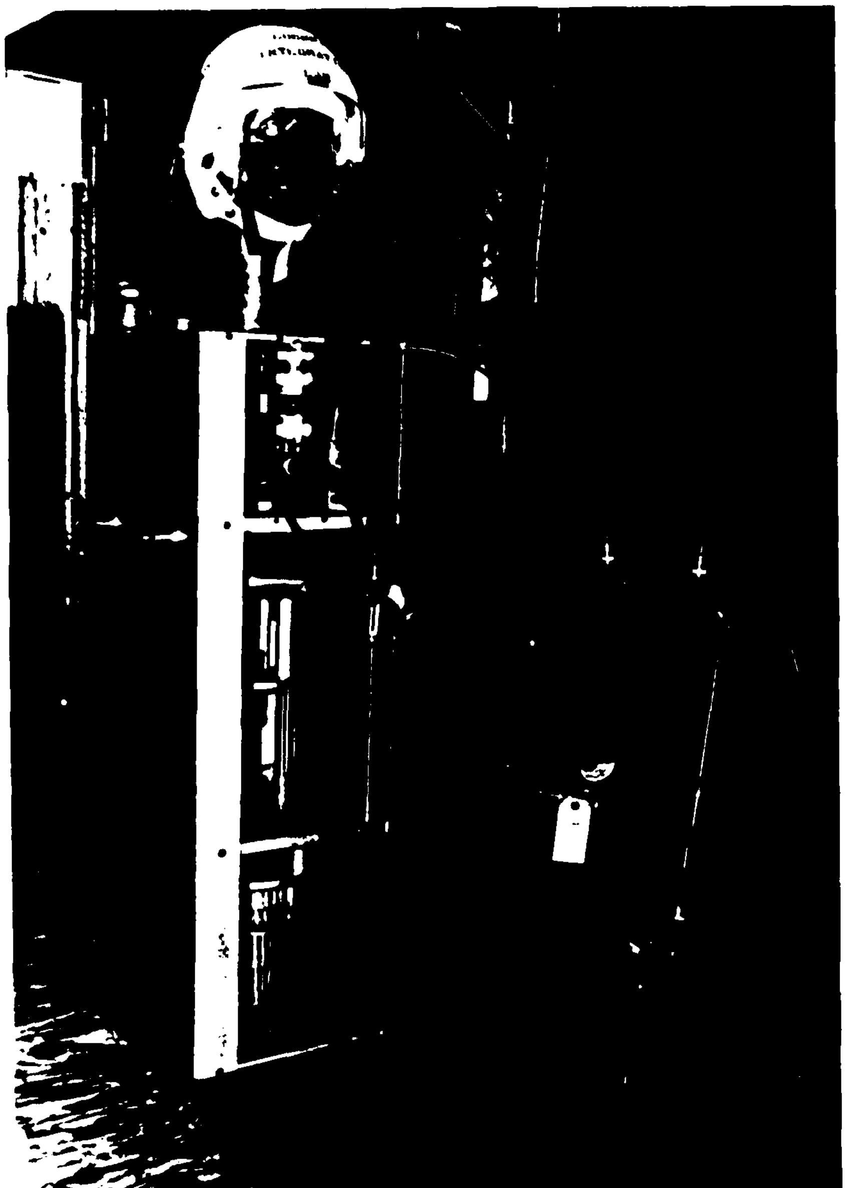

Figure 9. Test rig installed in the environmental chamber: <u>View b</u>.

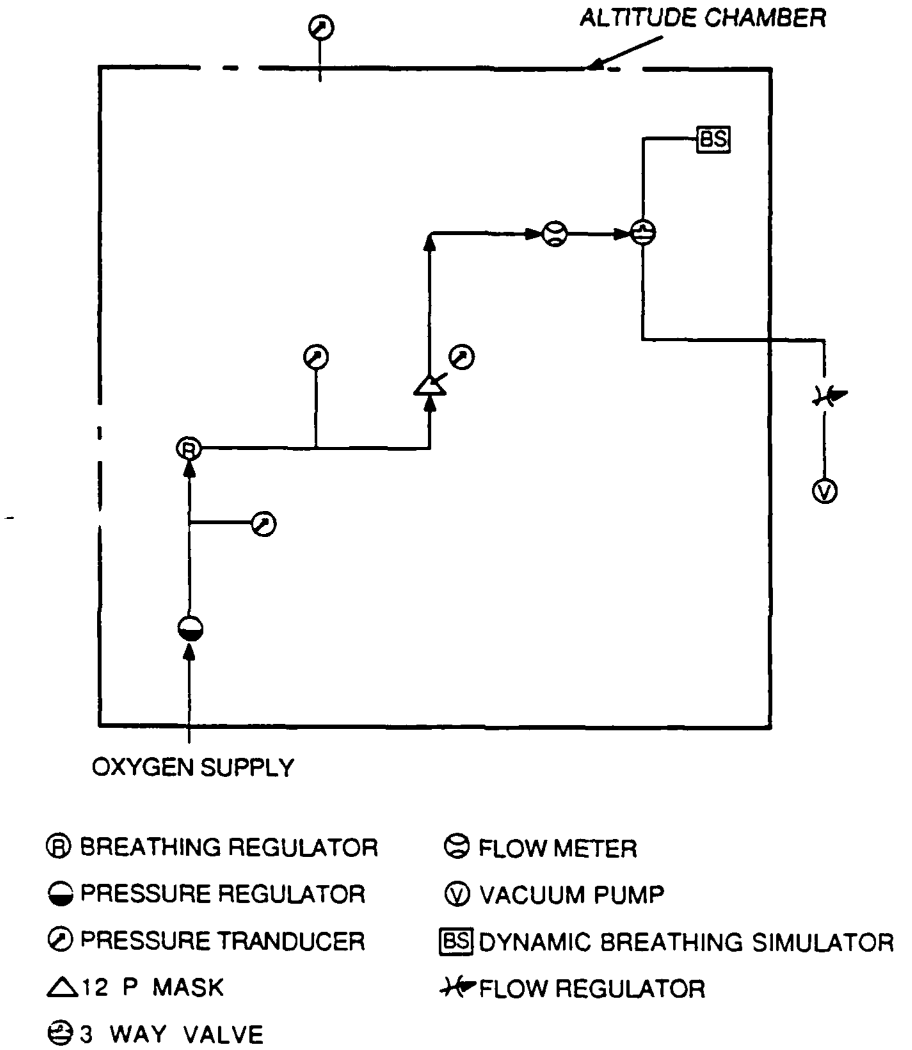

Figure 10. The B-1B MSOGS breathing regulator test setup.

Figure 11. One of two groups of human subjects who tested the system over a wide range of altitudes and breathing demands.

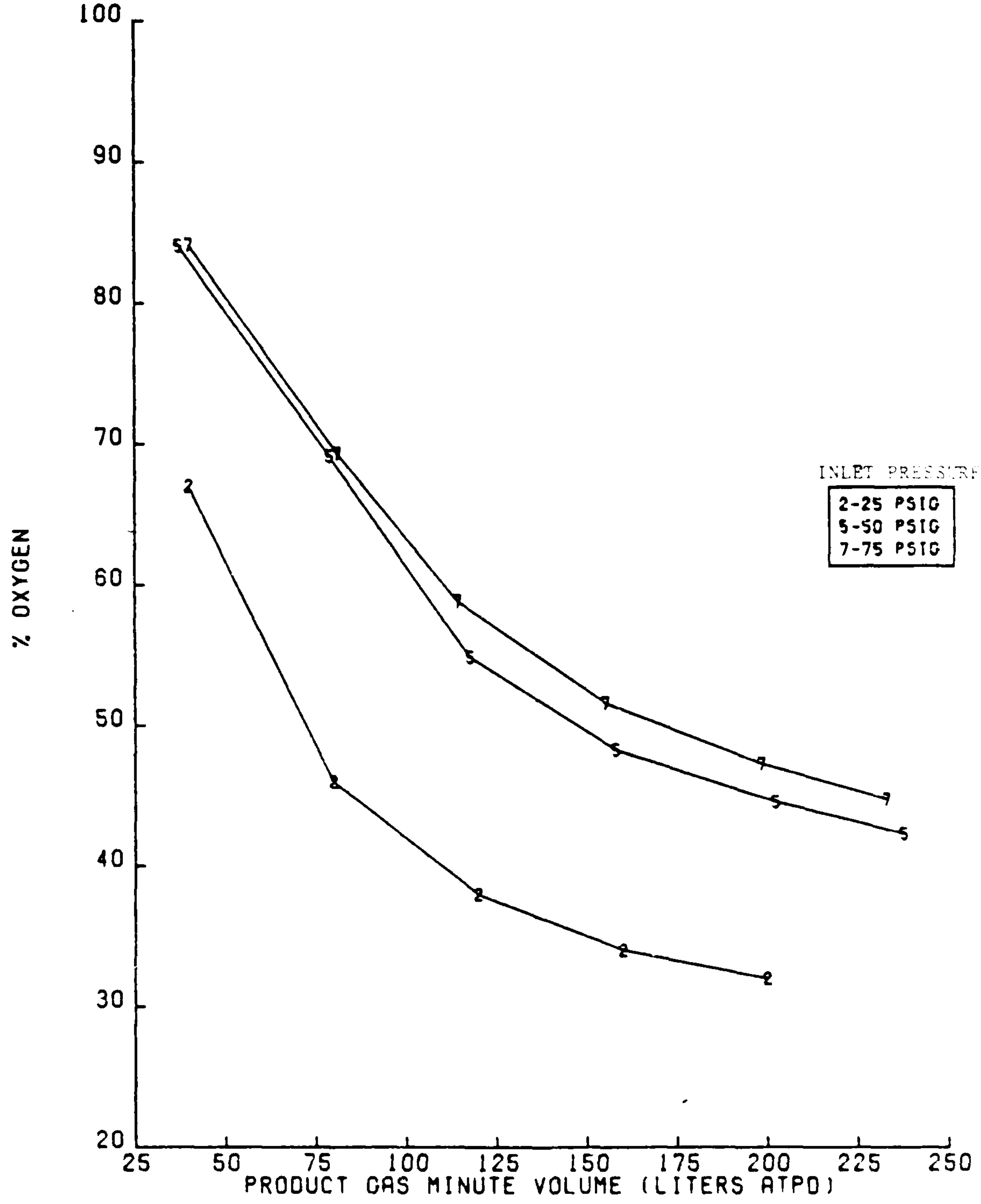

Figure 12. The B-1B MSOGS oxygen output at ground level, with CEB and inlet air at 72 ^{O}F.

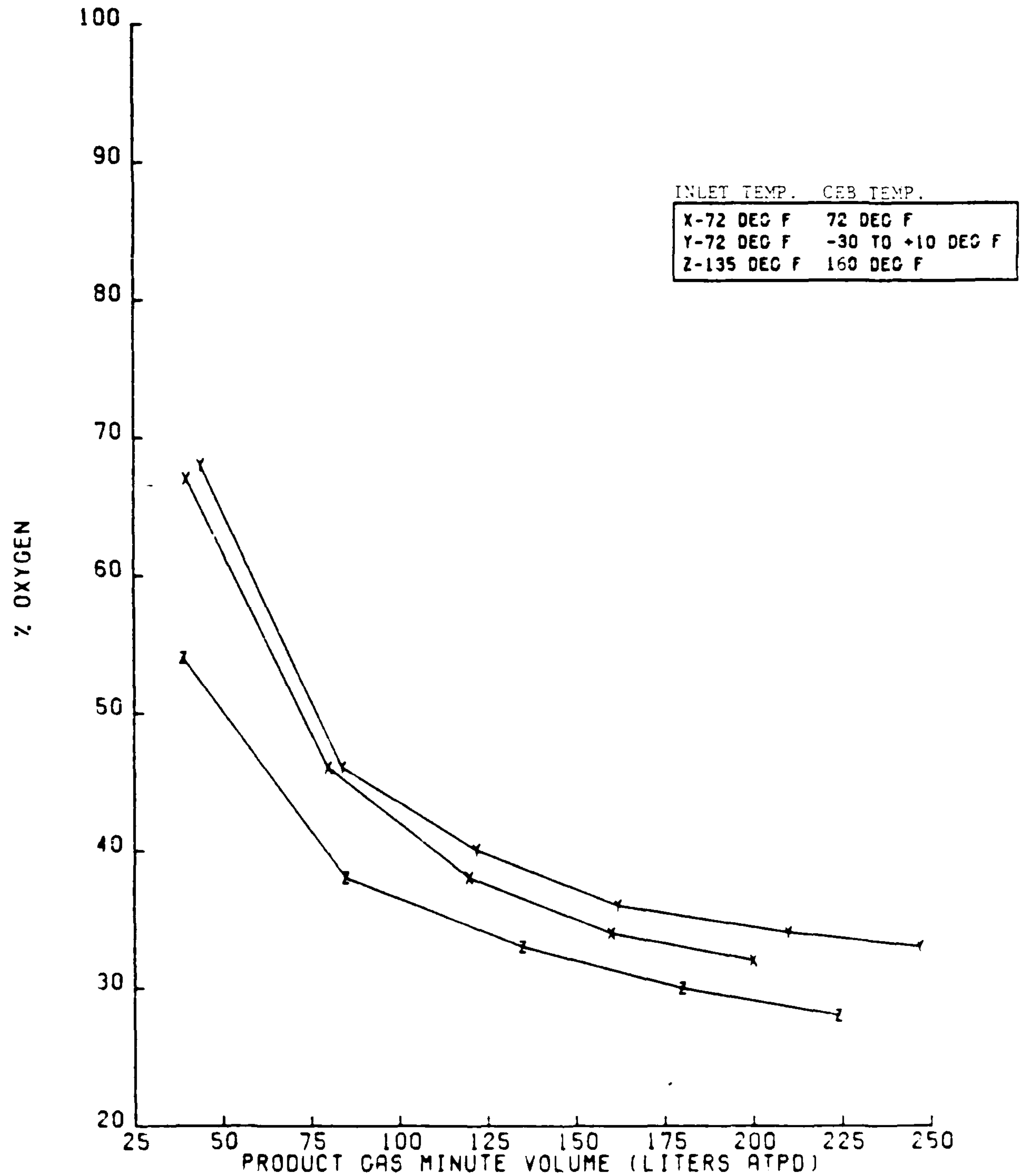

Figure 13. The B-1B MSOGS oxygen output at ground level with inlet air pressure at 25 psig, and temperatures as noted in figure.

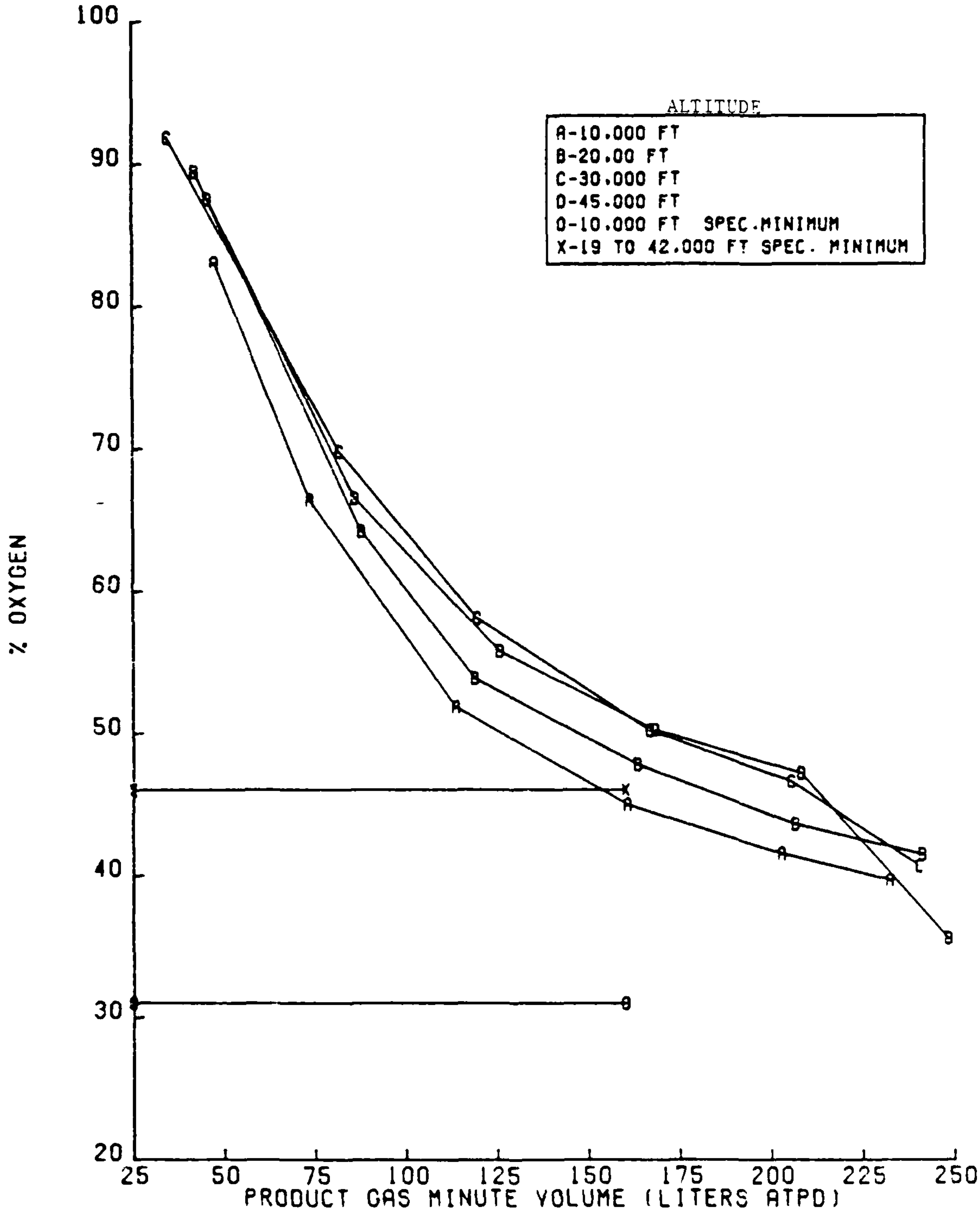

Figure 14. The B-1B MSOGS oxygen output in pressurized cabin with ambient conditions at 72 ^{O}F, and inlet air pressure at 25 psig.

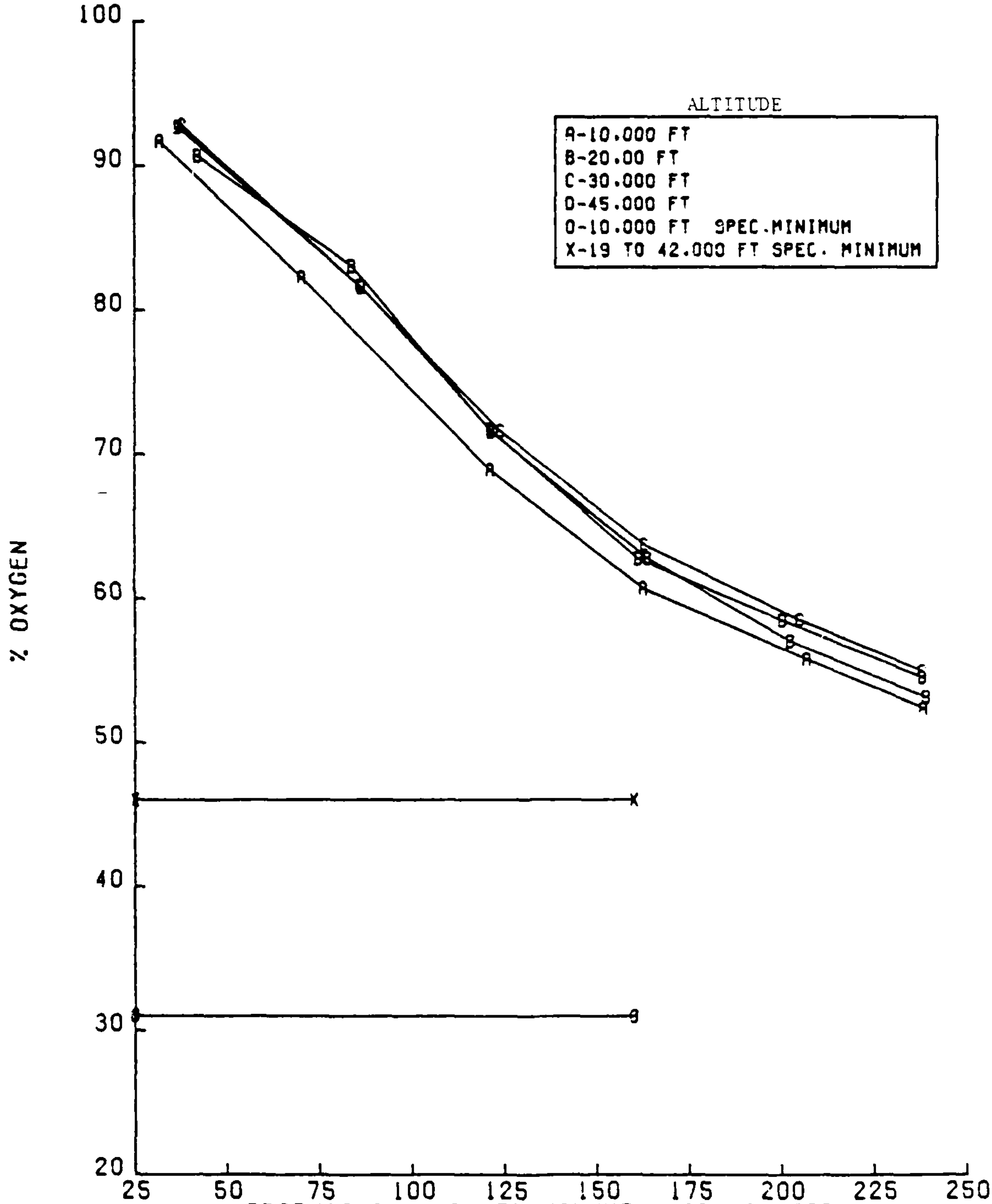

Figure 15. The B-1B MSOGS oxygen output in pressurized cabin with ambient conditions at 72 ^{O}F, and inlet air pressure at 50 psig.

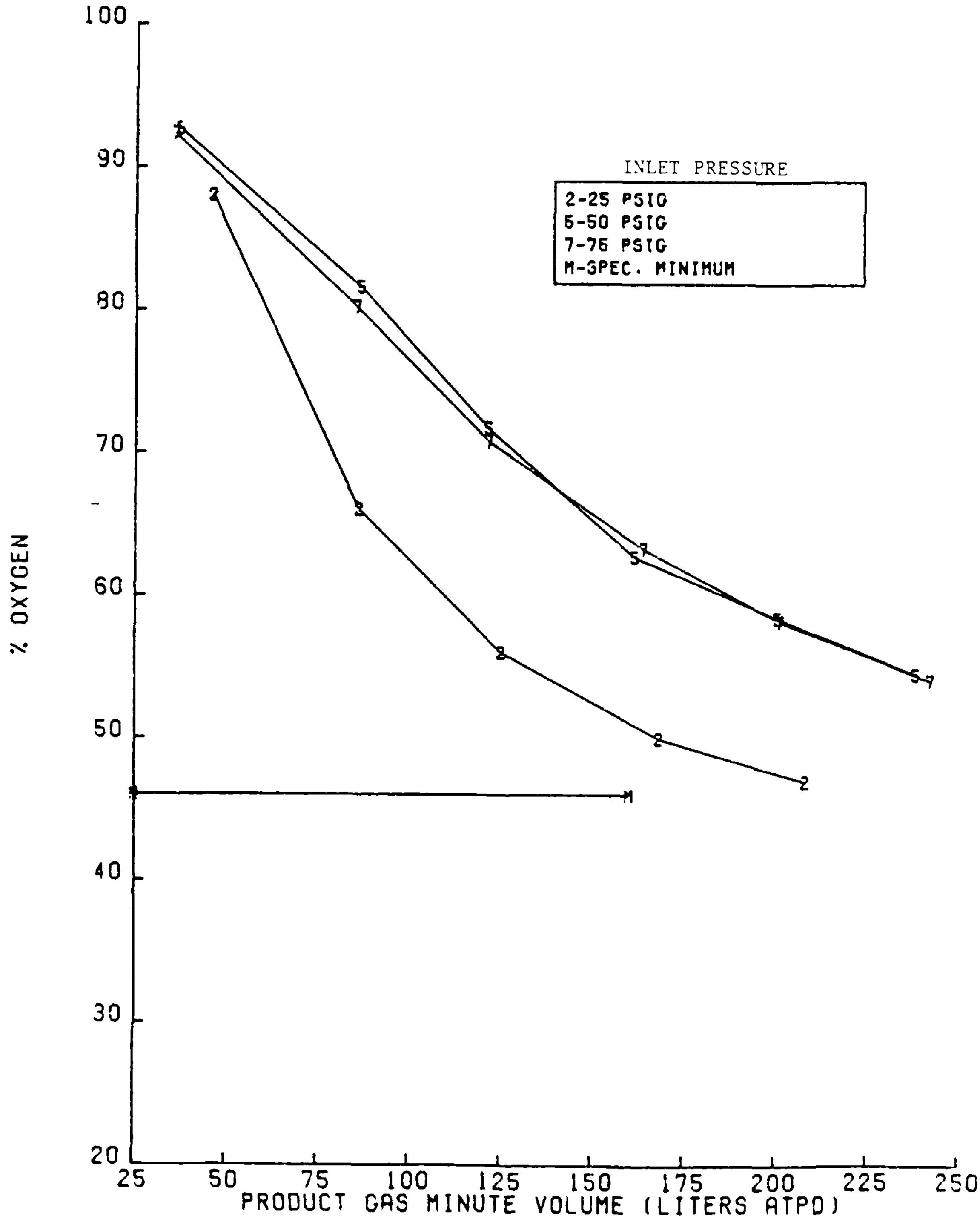

Figure 16. The B-1B MSOGS oxygen output in pressurized cabin, at altitude of 10,000 ft, and with ambient conditions at 72 °F.

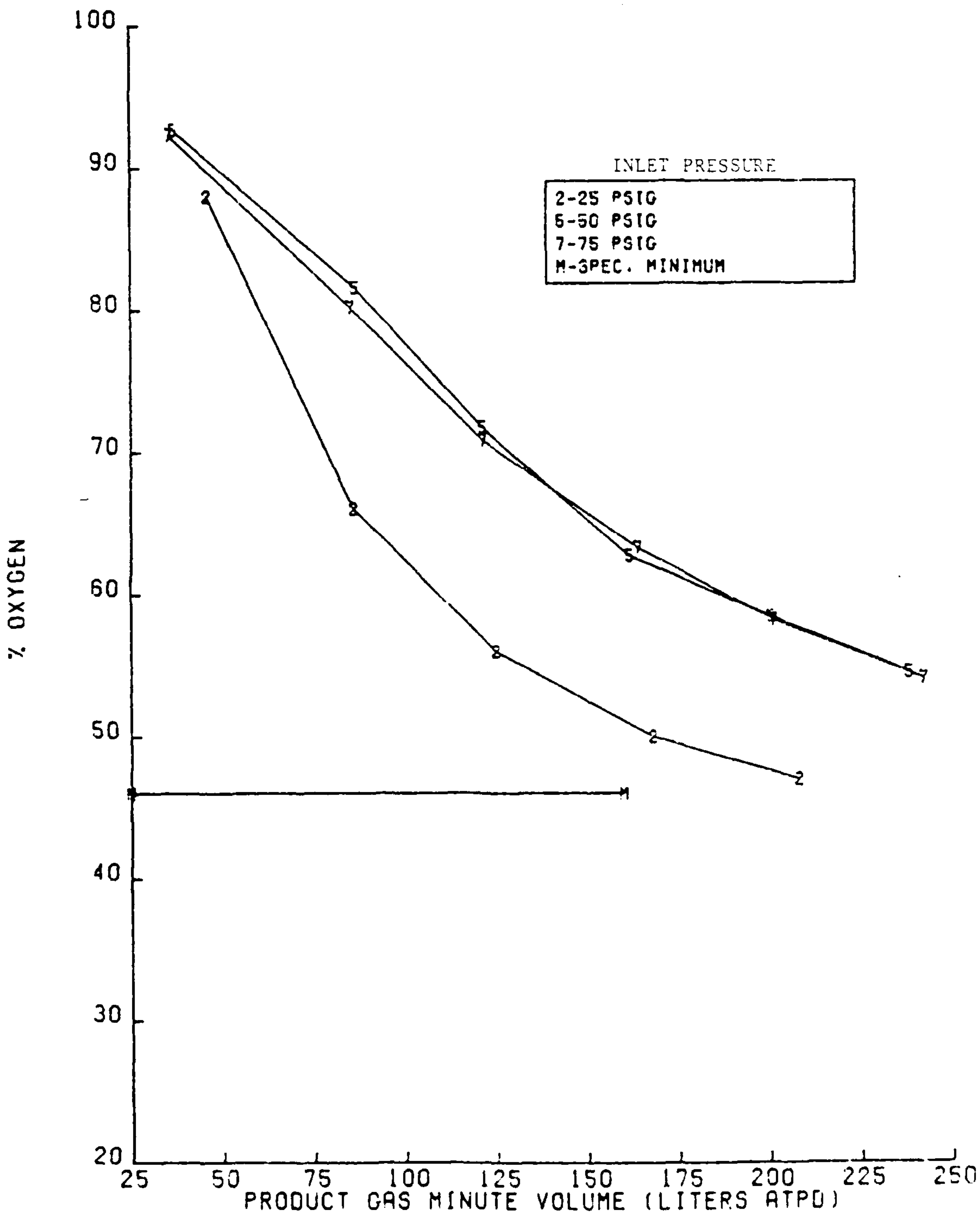

Figure 17. The B-1B MSOGS oxygen output in pressurized cabin, at altitude of 45,000 ft, and with ambient conditions at 72 ^{O}F.

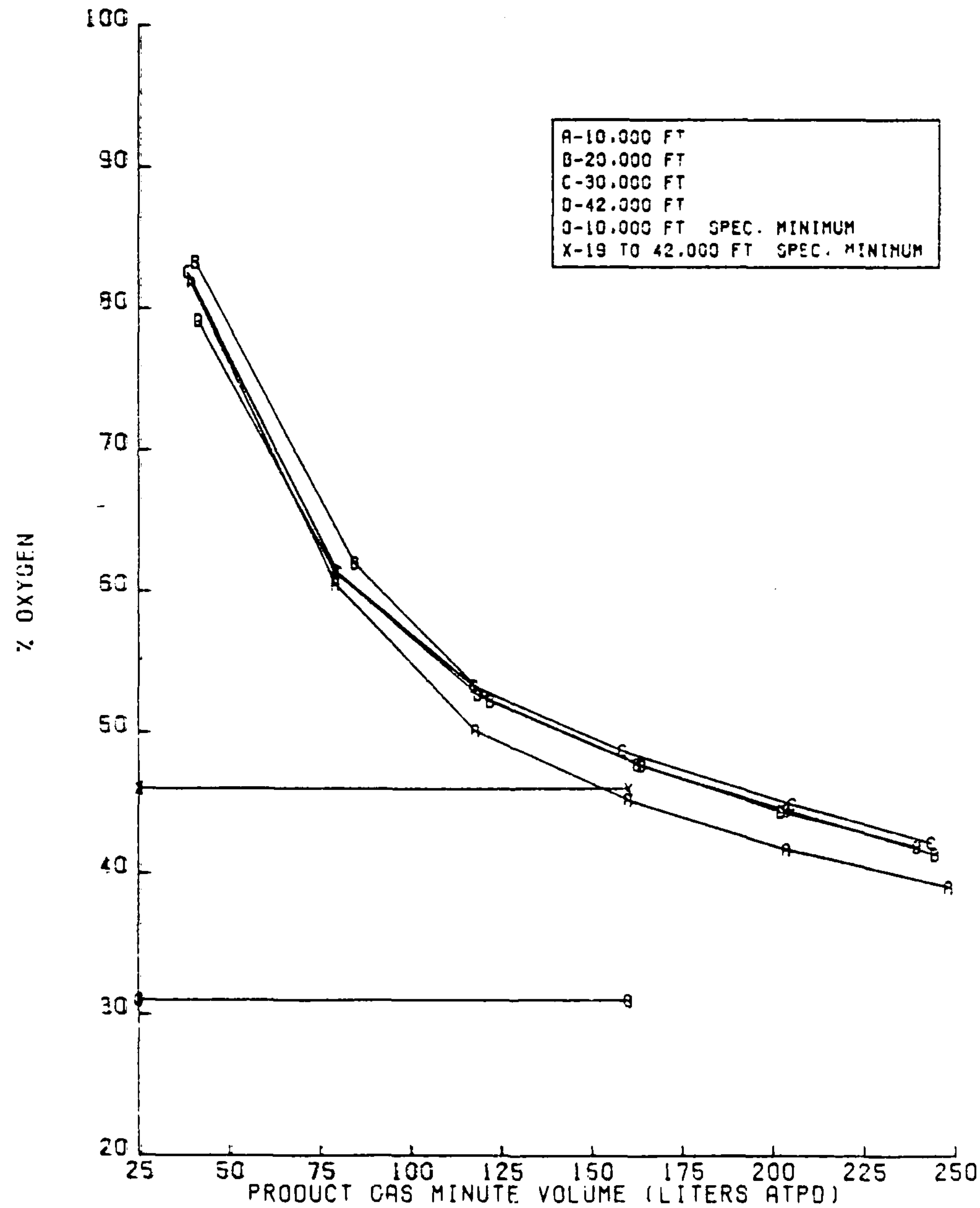

Figure 18. The B-1B MSOGS oxygen output in pressurized cabin, with inlet air at 100 ^{o}F and 32 psig, and CEB temperature at 120 ^{o}F.

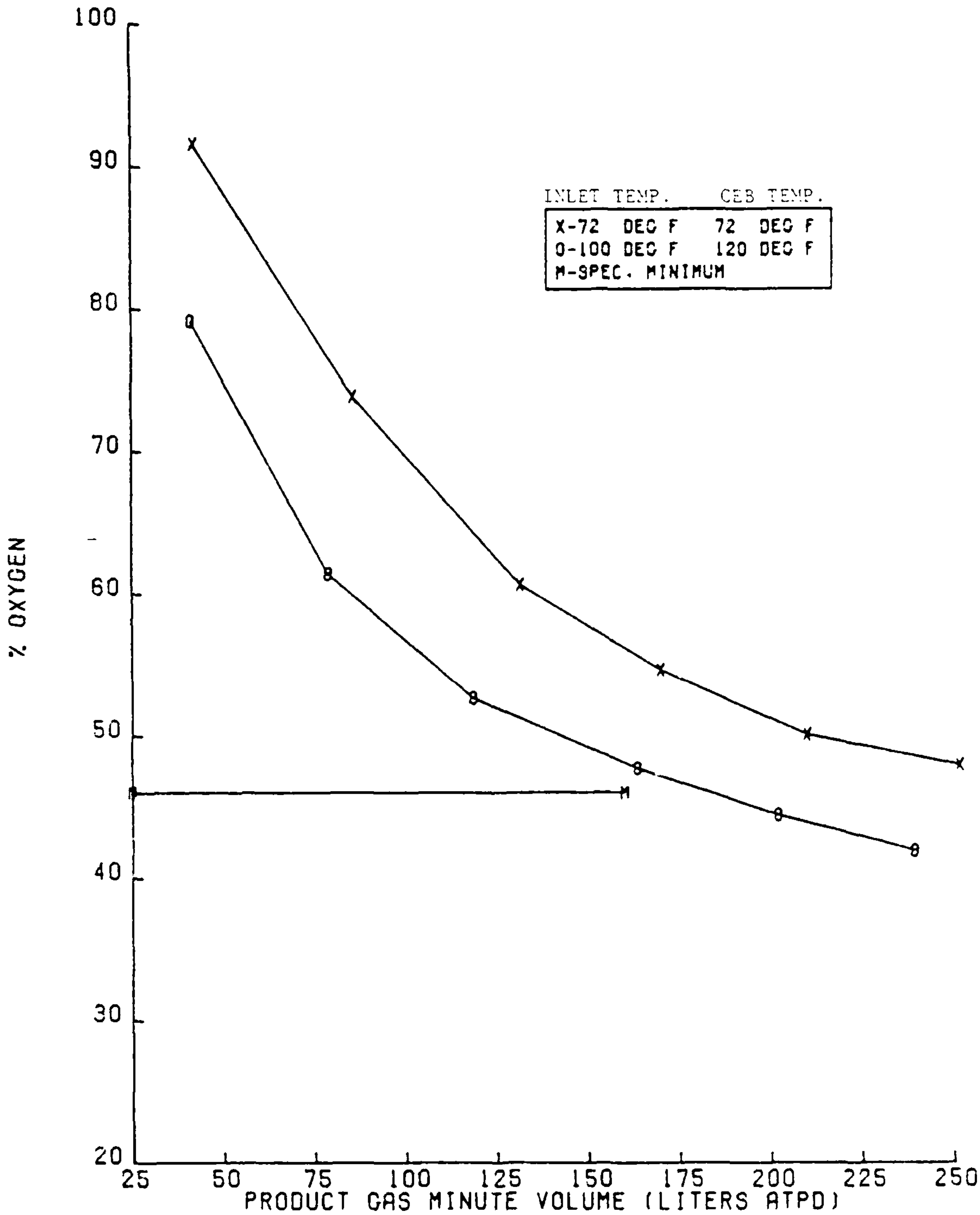

Figure 19. The B-1B MSOGS oxygen output in pressurized cabin, with altitude at 42,000 ft, inlet air pressure at 32 psig, and operating temperature as noted in figure.

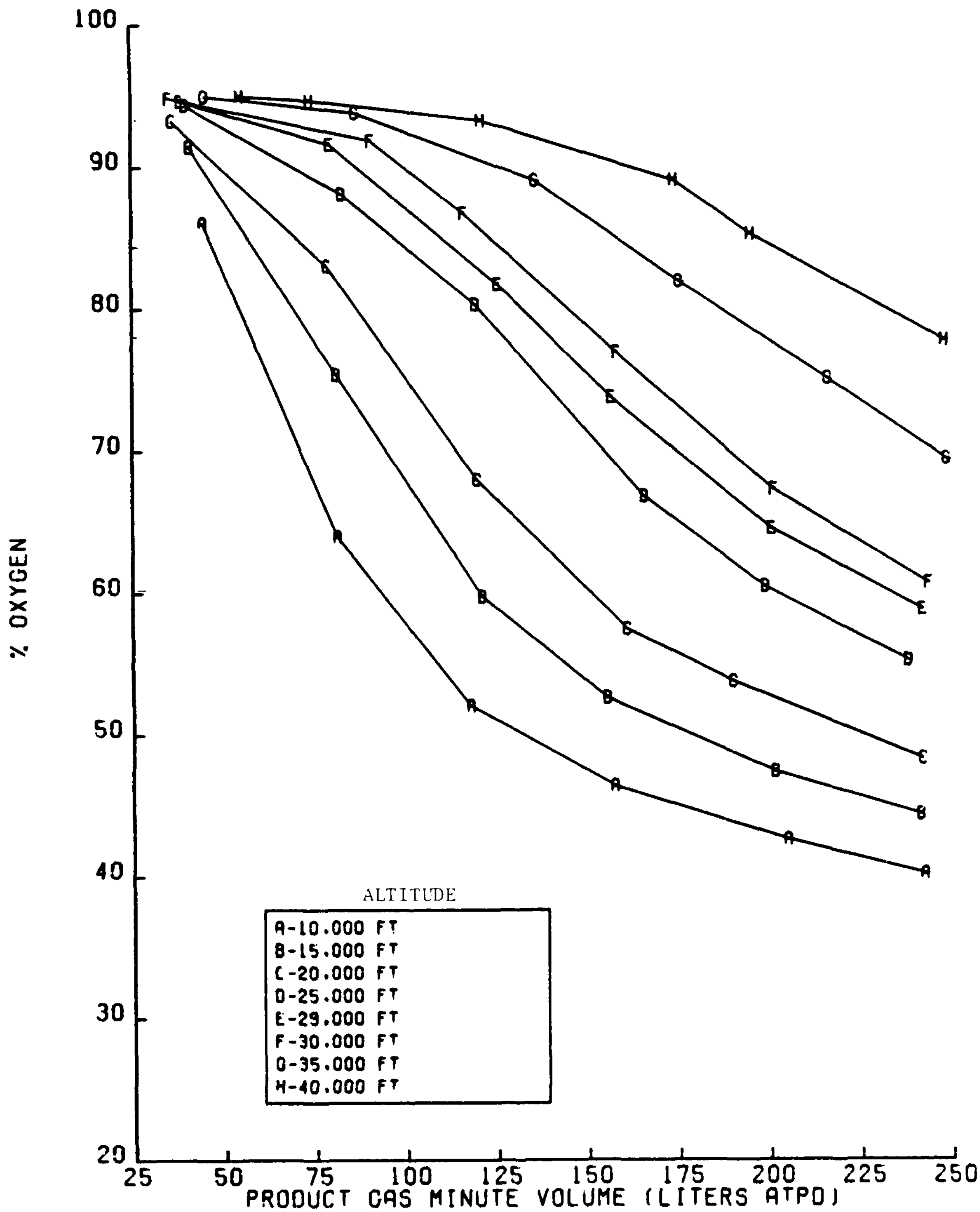

Figure 20. The B-1B MSOGS oxygen output in unpressurized cabin, with ambient conditions at 72 °F, and inlet air pressure at 25 psig.

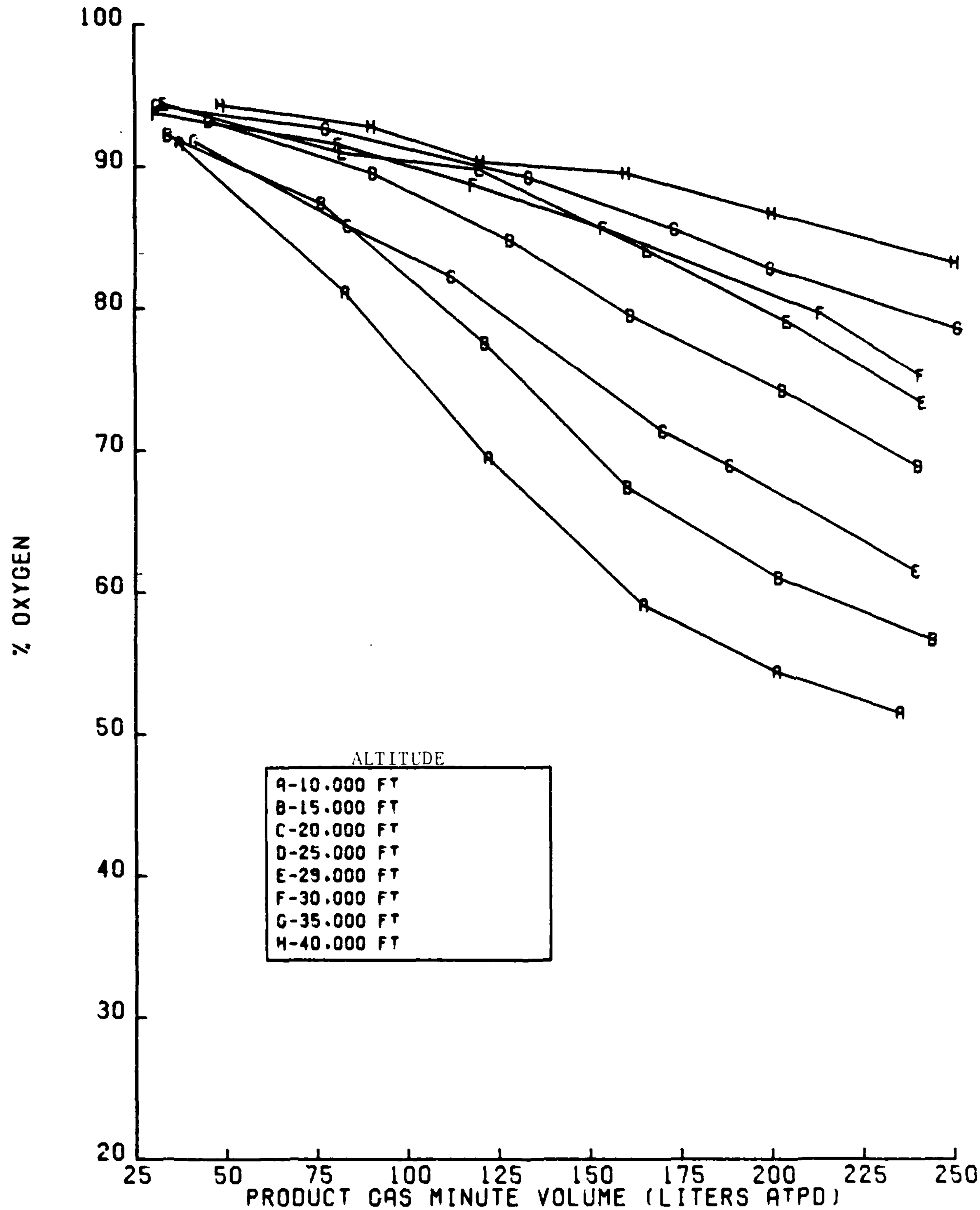

Figure 21. The B-1B MSOGS oxygen output in unpressurized cabin, with ambient conditions at 72 °F, and inlet air pressure at 50 psig.

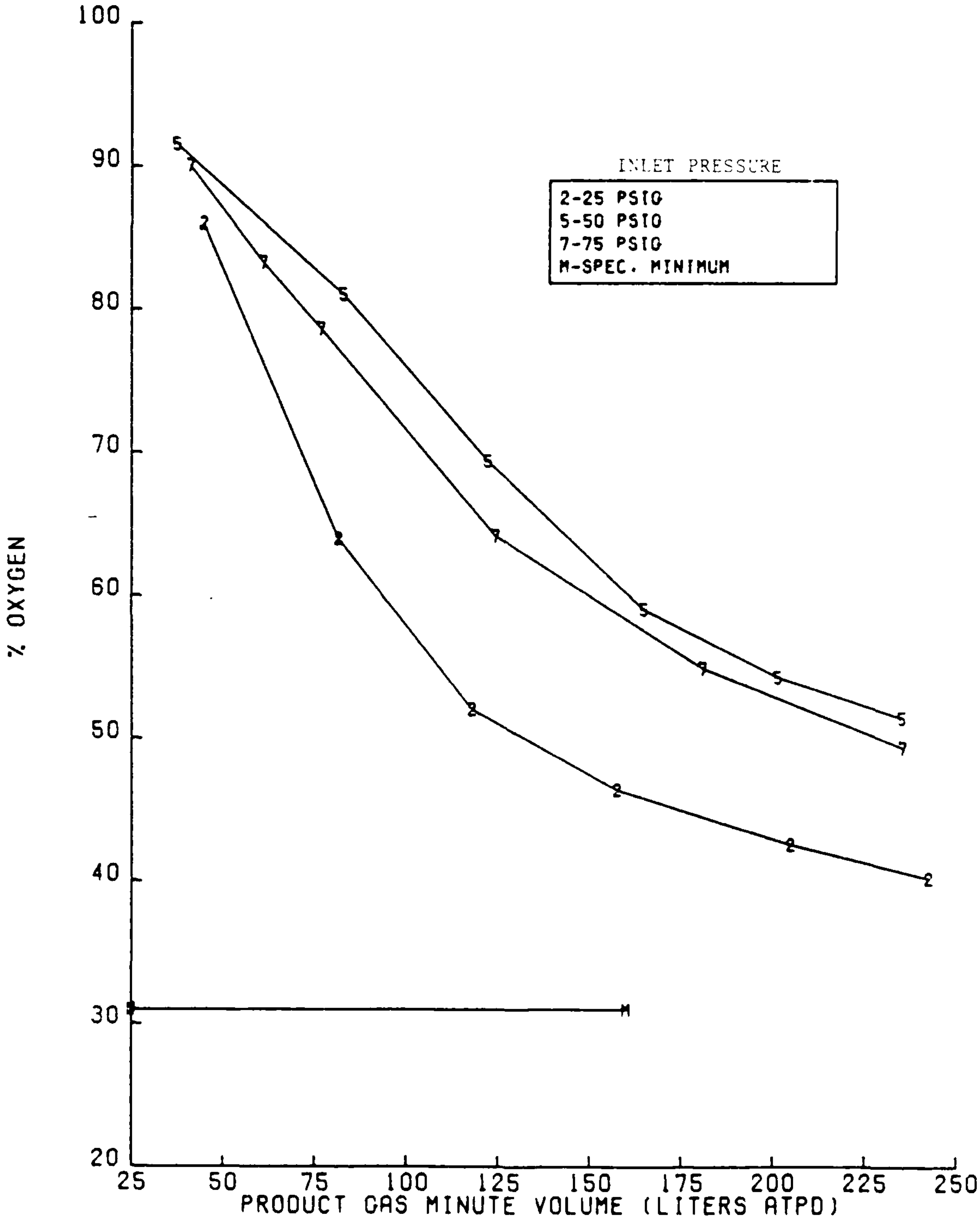

Figure 22. The B-1B MSOGS oxygen output in unpressurized cabin, at altitude of 10,000 ft, and ambient conditions at 72 °F.

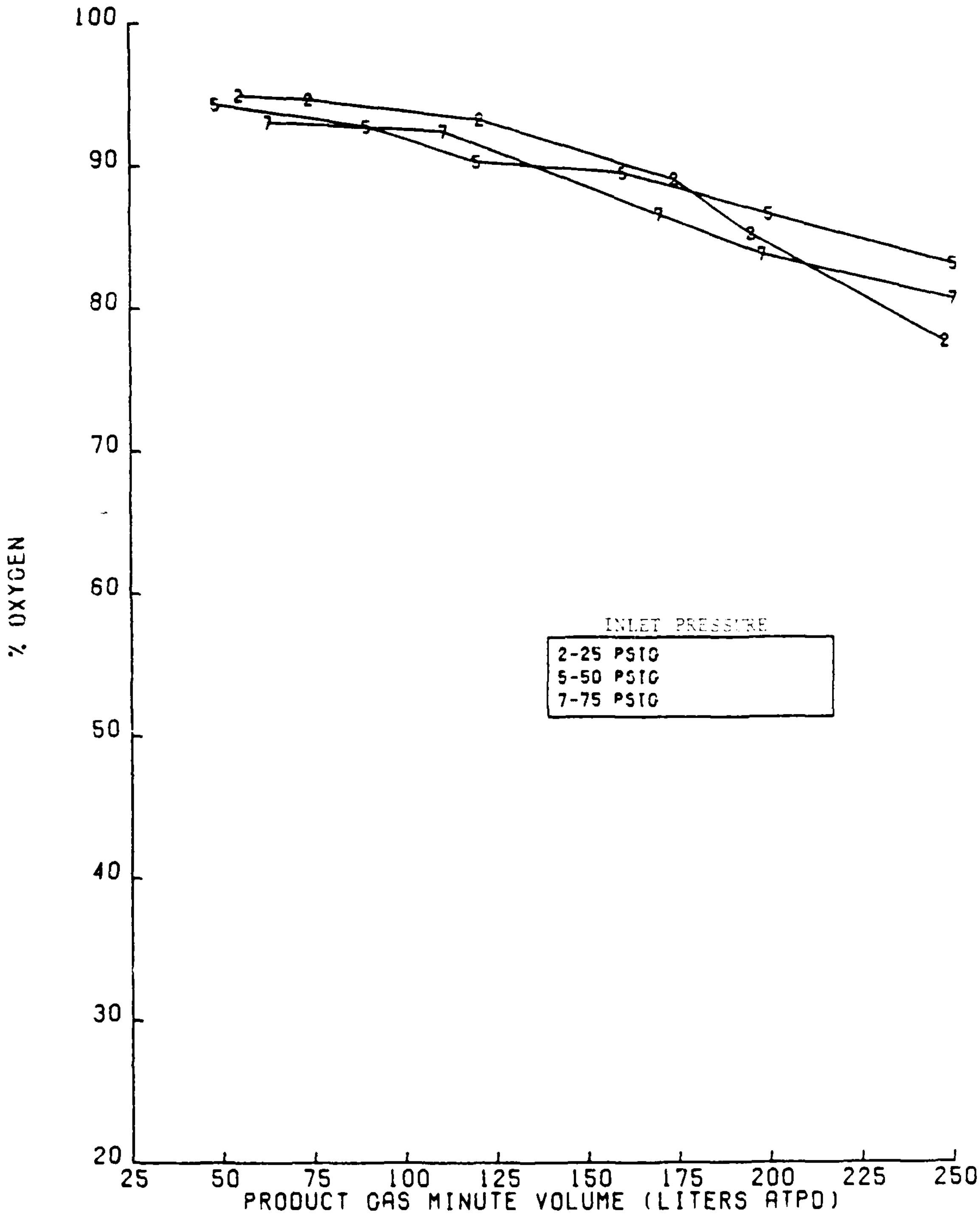

Figure 23. The B-1B MSOGS oxygen output in unpressurized cabin, at altitude of 40,000 ft, and ambient conditions at 72 °F.

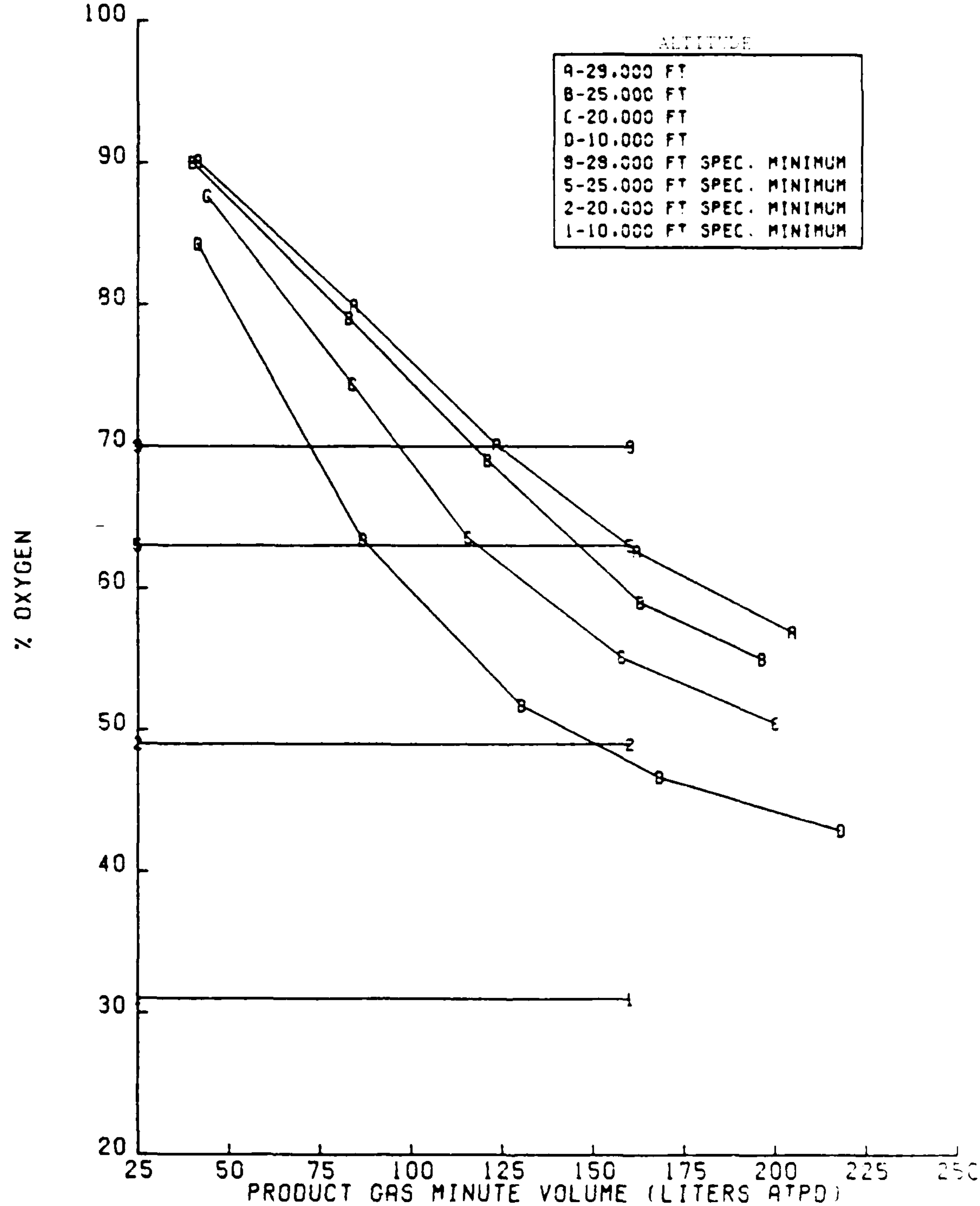

Figure 24. The B-1B MSOGS oxygen output in unpressurized cabin, with inlet air temperature at 100 °F, CEB temperature at 120 °F, and inlet air pressure at 32 psig.

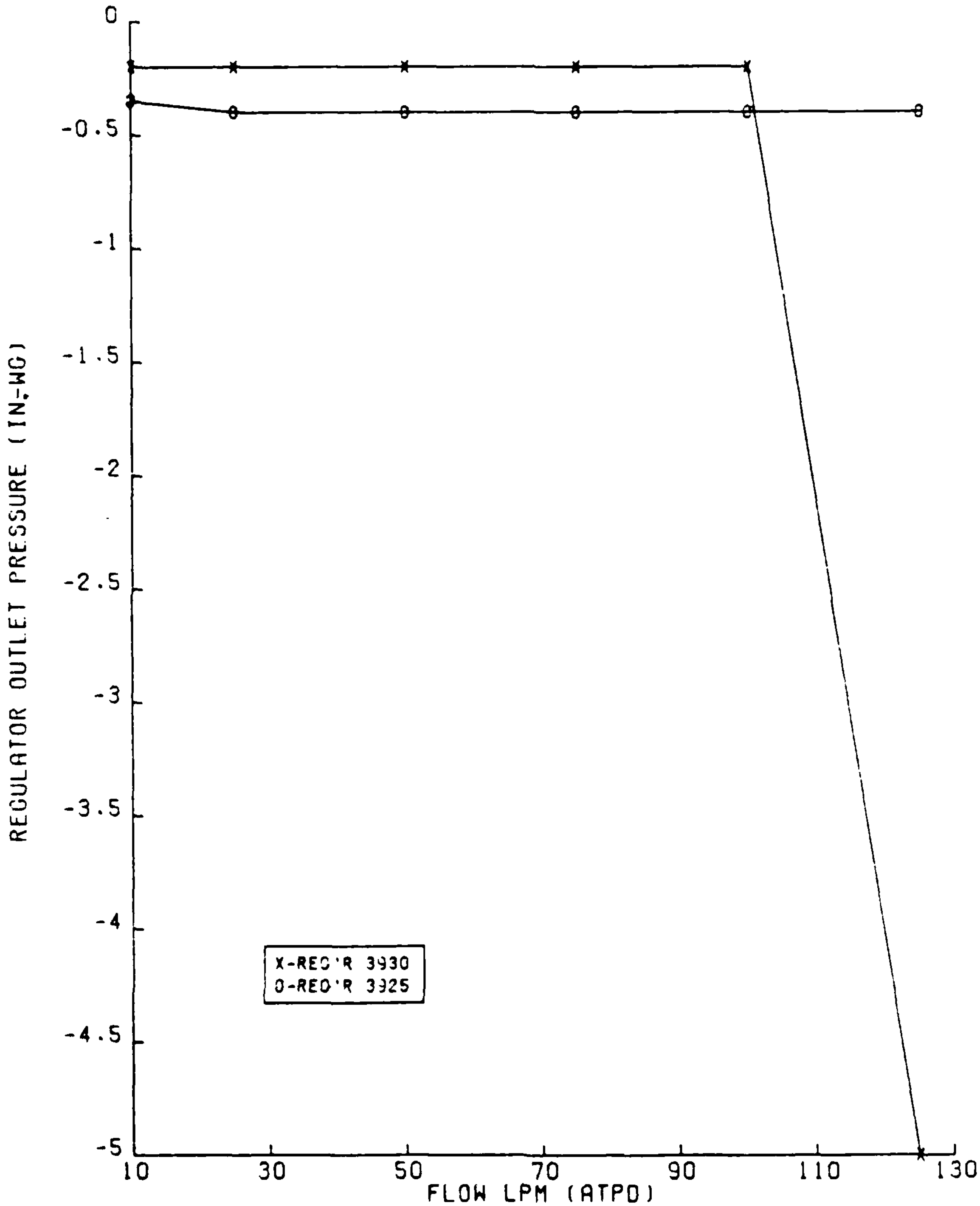

Figure 25. The B-1B breathing regulator steady-flow performance in the demand mode, with a regulator inlet pressure of 10 psig, and the cabin at ground-level pressure.

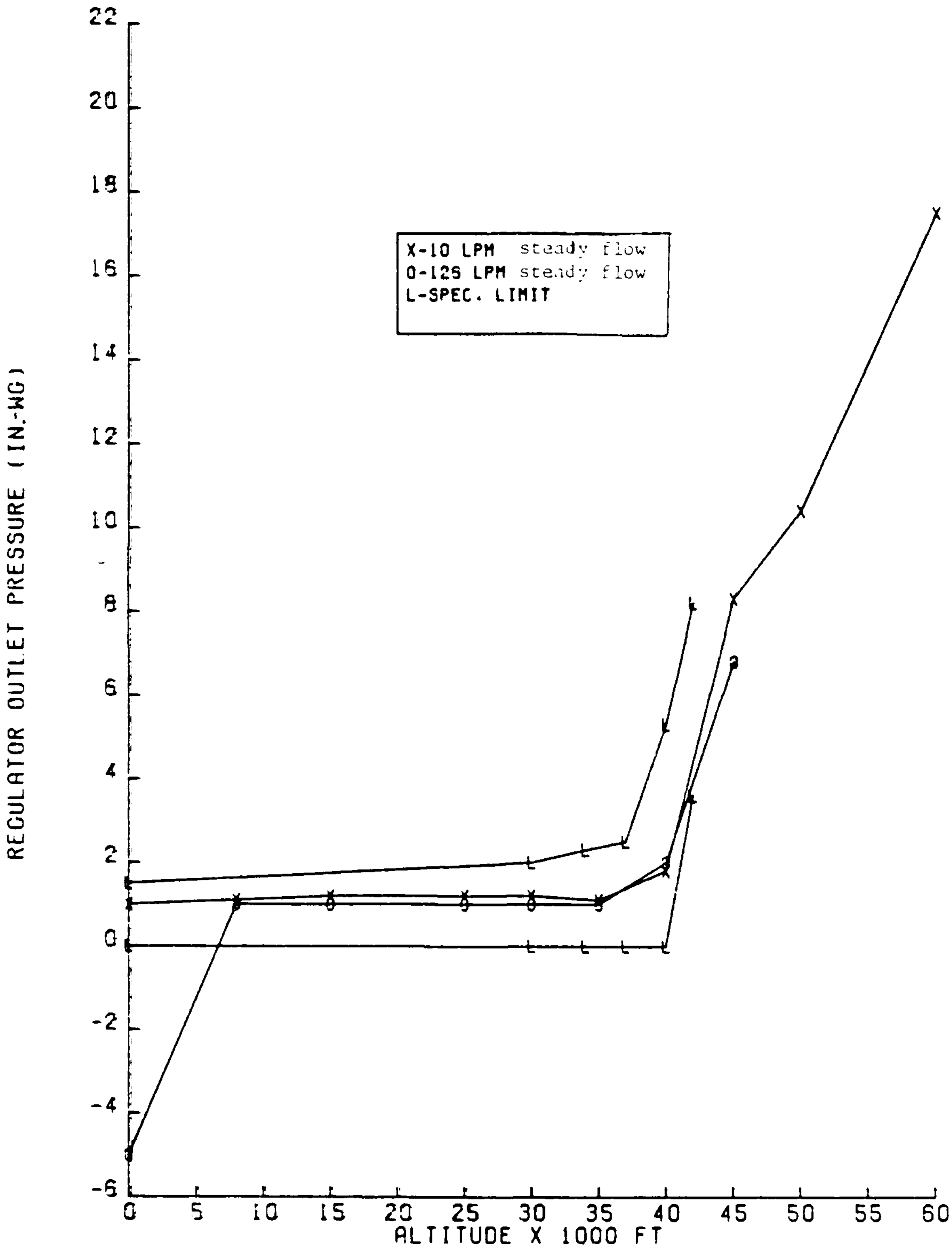

Figure 26. The B-1B breathing regulator pressure schedule with safety pressure, and with 10-psig regulator inlet pressure.

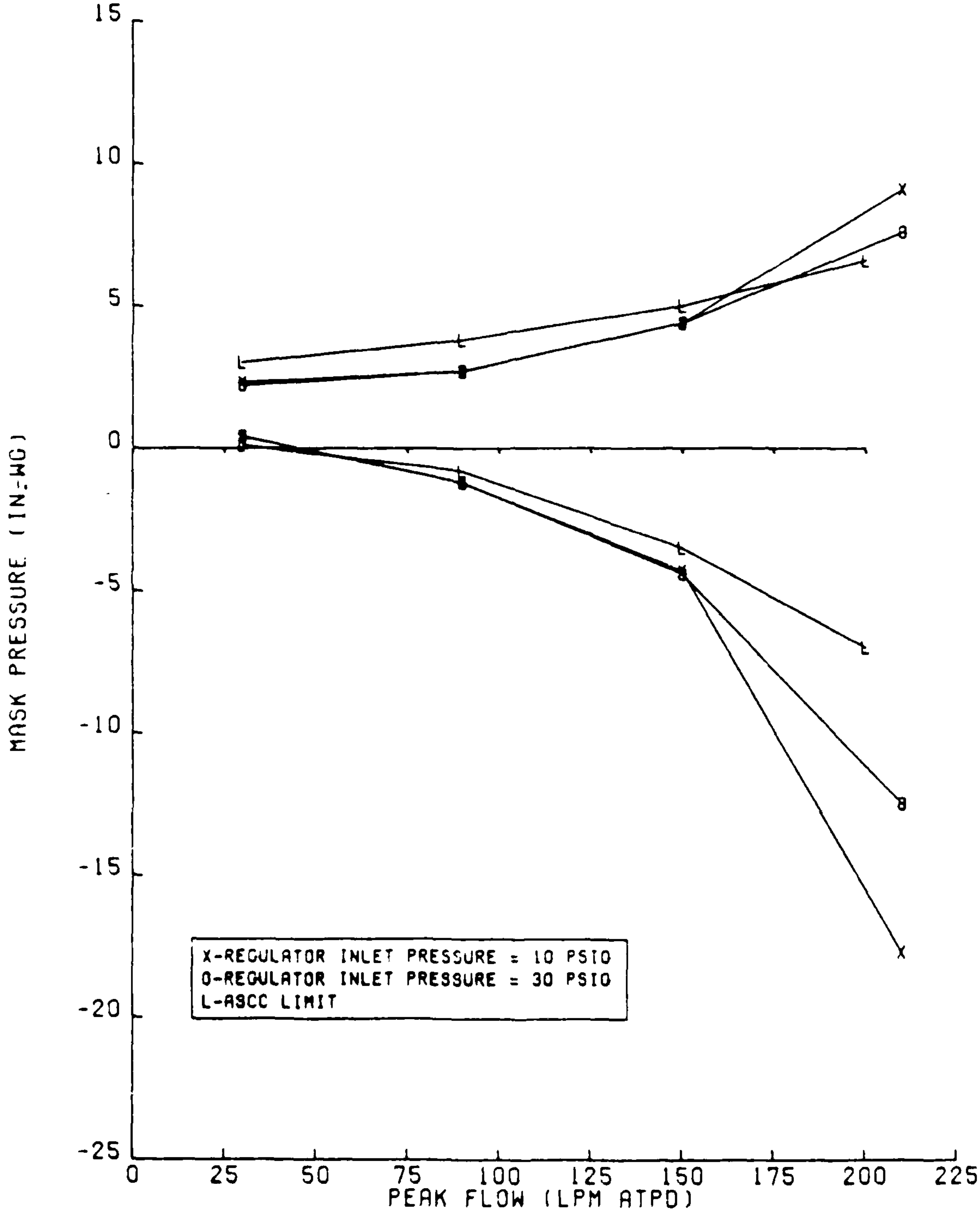

Figure 27. The B-1B breathing regulator performance at ground level with safety pressure.

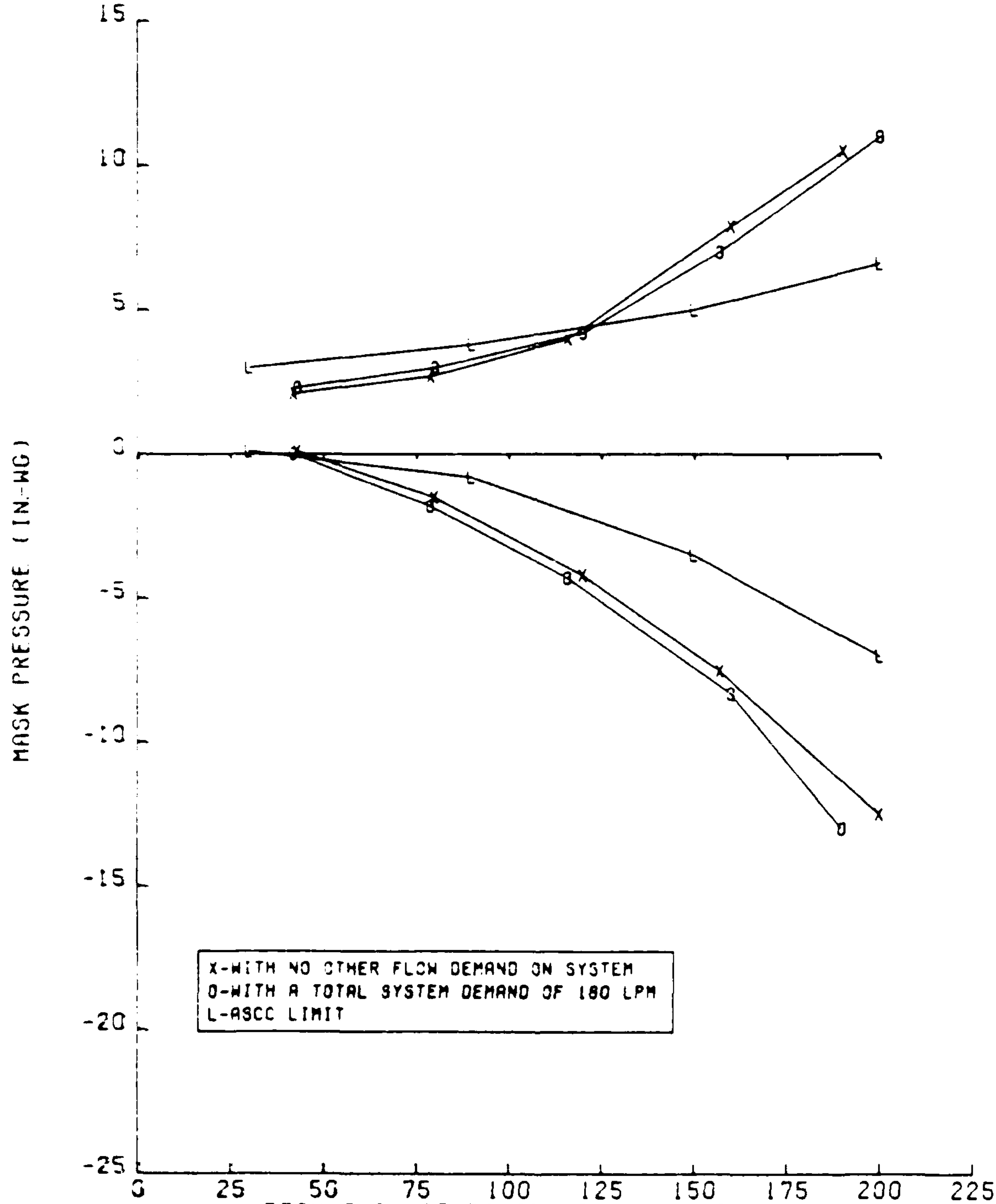

Figure 28. The B-1B MSOGS breathing performance in pilot station at ground level, with concentrator inlet pressure at 32 psig and regulator set on safety pressure.

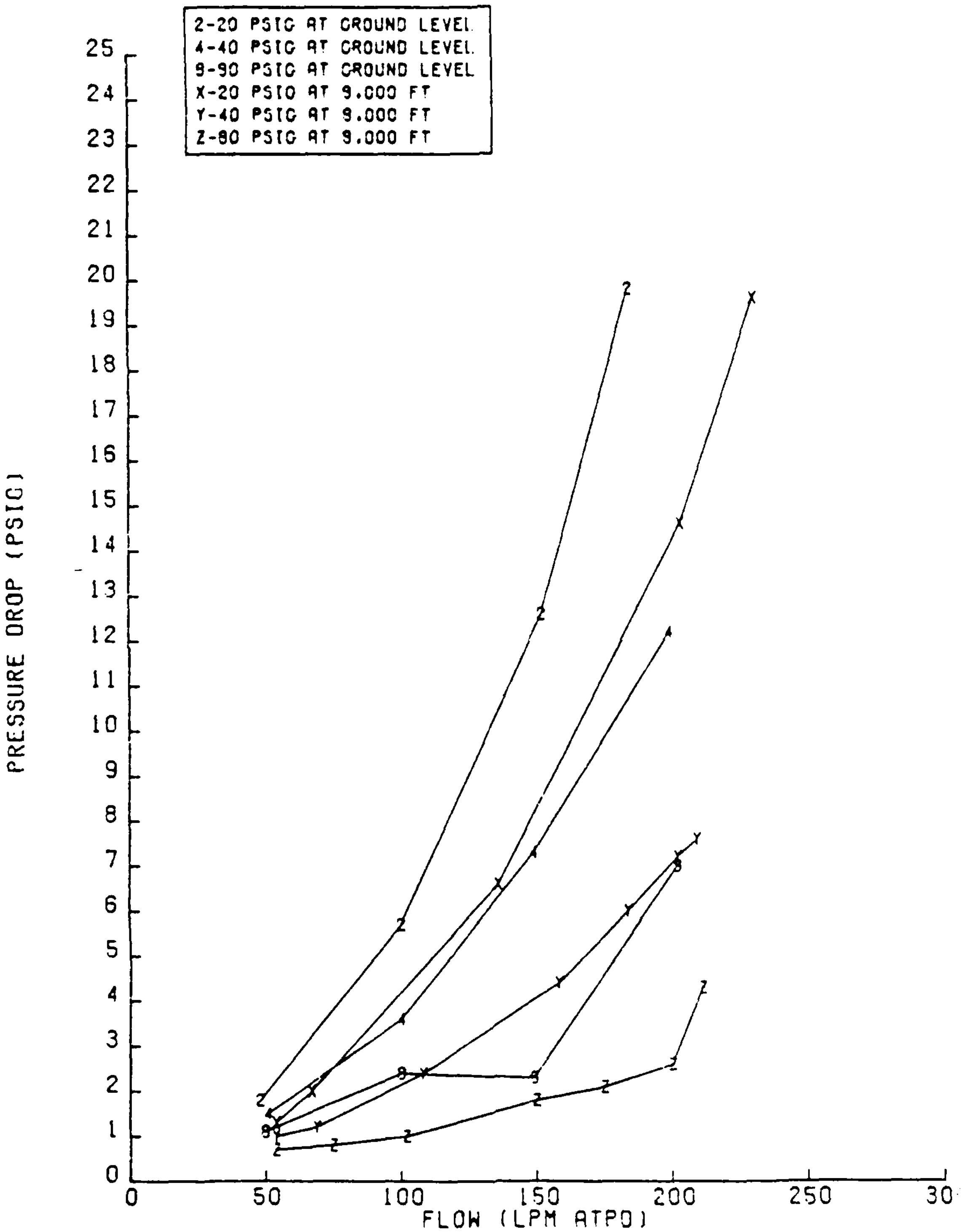

Figure 29. The B-1B breathing line pressure drop from the concentrator outlet to the regulator inlet at the pilot station, with cabin altitude and concentrator outlet pressure as noted in figure.

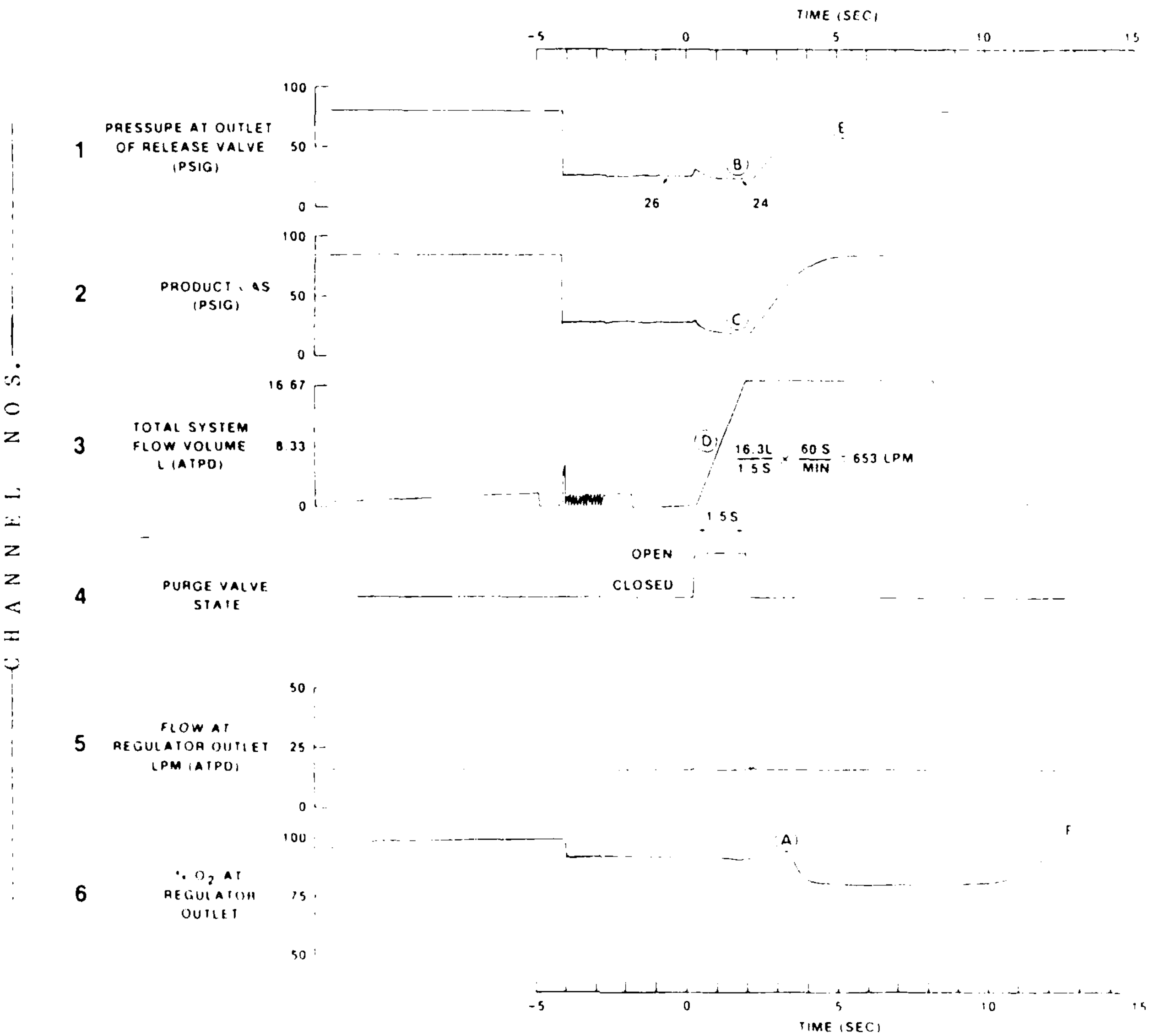

Figure 30. Oxygen delivery during simulated decompression.

ABBREVIATIONS AND ACRONYMS

ABO	aviator's breathing oxygen
ASCC	Air Standardization Coordinating Committee
ATPD	ambient temperature and pressure, dry
BOS	backup oxygen supply
CEB	central equipment bay
GL	ground level
in.-wg	inches of water, gauge
lpm	liters per minute
MSOGS	Molecular Sieve Oxygen Generation System
NORM	normal (mode)
PRESS	safety pressure (mode)
psig	pounds per square inch, gauge
RD	rapid decompression
USAFSAM	U.S. Air Force School of Aerospace Medicine

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